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Three Centuries of Vegetation Change in the William & Mary College Woods reconstructed using Phytoliths

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by

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Abstract

The College Woods, west of William & Mary's campus, consists of ~900 acres of protected southern mixed hardwood forest. The woods surround Lake Matoaka, a former millpond established in ~1700. Despite the rich history of the area, little is known about how the dominant vegetative landcover has shifted over the last 300 years. This study set out to quantify the modern vegetation within the College Woods via the phytolith assemblages within the soil and identify shifts in the assemblages since the creation of Lake Matoaka and whether these changes are distinct from the vegetation that existed in the area before the lake. To accomplish this, I studied the composition and preservation of phytoliths – silica bodies generated within and between plant cells. The study focused on the two questions: do the modern phytolith assemblages in the soil of the College Woods reflect the vegetation present and can phytoliths within the sediments of Lake Matoaka be used to identify the dominant vegetative communities over the last ~300 years? I addressed these questions with three approaches: 1) Identify the primary phytolith producing taxa within the College Woods; 2) Identify the modern phytolith assemblages within the soil of the College Woods; 3) Identify the differences between phytolith assemblages from the lake sediment core samples. I found the following: 1) The production of phytoliths varies heavily between and within different common taxa of the College Woods, with species of oaks (*Quercus spp.*) unpredictably producing phytoliths and beeches (*Fagus grandifolia*) likely contributing the majority of dicot phytoliths; 2) The modern phytolith assemblages of the College Woods reflect a low phytolith producing environment, and the vegetative homogeneity is reflected in the phytolith record; 3) The phytolith density between 1700 and 1810 indicates an increased presence of grasses likely due to a major shift away from forested landcover. Before the lake, the landcover was distinct from all vegetation post-1700 indicating the natural vegetative community of the pre-lake has not returned to the area despite being protected for nearly a century.

Introduction

Lake sediments provide valuable insight into reconstructing past environments within and around a drainage basin. Sediment cores provide the means to reconstruct paleoclimates, determine lake productivity changes, estimate past water levels, and interpret past ecosystems. For example, pollen within lake sediments can be used to reconstruct vegetation (Minckley et al., 2007) and eDNA can be used to reconstruct fauna from within the water column (Ficetola et al., 2008). Another method of analysis that has become increasingly popular is the use of phytoliths in paleoecological reconstructions, especially during the Quaternary (Strömberg et al., 2018). Phytoliths are microscopic amorphous silica (SiO_2) bodies produced within plant cells and intercellular spaces (Piperno, 2006). Like pollen, they are present within lake sediments and used as proxies for surrounding vegetation. Phytoliths capture the composition of the local vegetation growing within a drainage basin in ways that pollen fails (Yost et al., 2013). They are formed as assemblages within sediments following plant decay and death in place, enabling studies to occur at the resolution of the sedimentation and soil formation rate. The mineralogical composition of phytoliths also makes them more durable than other biogenic microfossils, including pollen (Rovner, 1983). These qualities make phytolith analysis a viable method to study vegetational changes on shorter timescales of centennial and even decadal scales without the same chance of long-range aeolian drift as possible with pollen.

There is a great deal of importance in studying the Holocene (~11,650 – present) due to the impact humans have had on the world. In the last 300 years alone, humans have cleared 30% of the planet's forest to create agricultural land (Goldewijk, 2001; Pielke, 2005). Deforestation has substantial impacts on local environments and the earth's climate, influencing erosion, albedo, and removing essential habitat (Davin and de Noblet-Ducoudré, 2009). The release of

greenhouse gases into the atmosphere alters the climate as well and the impacts of human-induced climate change dominate the political and scientific discourse around the future. The magnitude of human-induced climate change is significant in its scope and there is value to examining the impacts of human activities in recent antiquity. This research seeks to provide additional evidence for these on landscapes over the last 300 years.

This study focuses on how local vegetation surrounding a former mill pond, Lake Matoaka within the College Woods (37.266233˚N 76.723547˚W) has changed over the last 300 years. I tested the potential for vegetational changes using phytolith assemblages extracted from modern soils in the watershed of the lake and from a lacustrine sediment core (LMP-03-16, Balascio et al., 2019). An effort to study human-landscape relations through the medium of vegetation is best conducted through localized records. Phytoliths form within plant cells or the interstitial spaces and reflect the shape of the space they form within (Piperno, 2006; Nawaz et al., 2019; Rashid et al., 2019). Dead and decaying plant tissues deposit phytoliths in the underlying soil matrix. Phytoliths, much like the soils or sediments in which they are deposited, are subject to transport by erosional forces. Unlike pollen, which is heavily biased towards transport via long and short range aeolian processes, phytoliths fail to travel beyond the limits of the sediments in which they are embedded. Following deposition, phytoliths have a chance of secondary dispersion under fluvial forces but are typically constrained to the bounds of a watershed (Madella and Lancelotti, 2012). In this case, the phytoliths observed within the lake core likely came from the drainage basin and were not transported from a distant location via wind. Phytolith morphology enables the researcher to identify these fossils to different levels of plant taxonomic groupings, with plants within the Poaceae family producing the most diagnostic and abundant phytolith forms (Piperno, 2006). As a result, I used the ratio of dicotyledon and

monocotyledon types as a representation of vegetation dynamics in the modern woods and the previous communities reflected in the lake core. I described how the vegetation within the College Woods has changed on a community level and I tested the ability to detect those changes within the phytolith record of Lake Matoaka.

Background

History of Lake Matoaka

Williamsburg, Virginia, located on the Virginia Peninsula in the Mid-Atlantic region of the United States, is among the longest continually inhabited areas by European settlers in North America, dating back to the settlement of Jamestown in 1607. Before the European settlers, Indigenous Americans had called the region home for thousands of years (Bragdon, 2001). The coastal plain of Virginia was home to many communities, most notably the Algonquin-speaking communities that coalesced into the Powhatan Confederacy (16^{th}-18^{th} century CE) (Gallivan, 2016). These communities lived a subsistence lifestyle of hunting, fishing, and farming. Ethnohistoric and ethnographic research with the descendant communities of the Powhatans during the 20^{th} century supports a model of agriculture conducted with slash and burn practices and abandoning patches for secondary succession once they fulfilled their use (Maxwell, 1910; Roundtree 1990, 2013a, b). Following their arrival, European settlers quickly spread across the East Coast intensifying the landscape modification by cutting down forests, draining marshes, and damming creeks (Brush, 2009). **Figure 1** illustrates the extent of landscape alteration on a regional scale done by humans in the Chesapeake Bay area over the past 300 years. The lengthy history of landscape modifications by humans makes the Virginia Coastal Plain a region rich with potential for examining the impact humans have had on the composition of the vegetation.

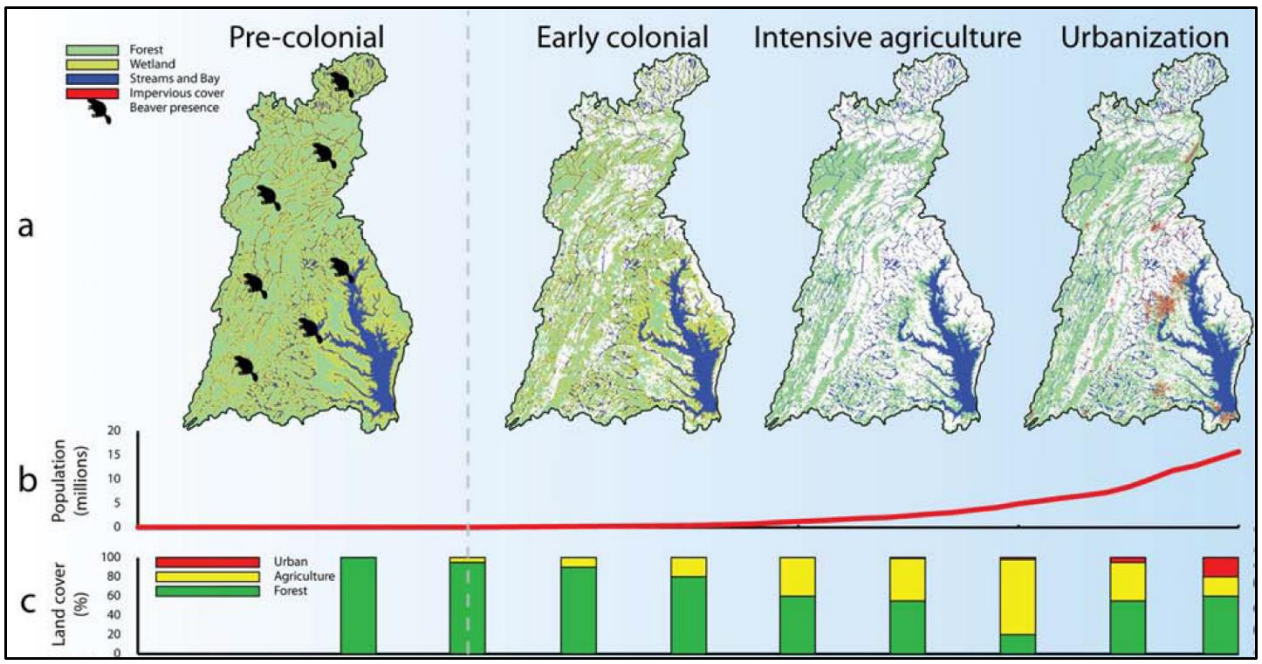

Figure 1: a) Map of landscape cover within the Chesapeake Bay drainage basin throughout different significant eras. The site of this study is in the lower right portion of the drainage basin. Important to note the decrease in almost all wetlands and the clearing of a majority of the forests in the area. b) Graph of the population living within the Chesapeake drainage basin through the same periods as the above maps. c) Graphic illustrating the percentages of different landcover types and how they change through time. Note the large increase in agricultural land, most of which is subsequently abandoned, becoming secondary growth forests such as the College Woods. Reproduced from Brush, 2009.

Lake Matoaka Vegetation History

Lake Matoaka is located immediately west of William & Mary's central campus in Williamsburg, Virginia. Bound by the York River to the North and the James River to the South, the lake sits within the watershed of the College Creek, a tributary of the James River. The region is a mixture of secondary growth forests, wetlands, agricultural fields, and urban centers (**Figure 2**). I chose to study the record within Matoaka because it is one of the oldest continual mill ponds in North America (Balascio et al., 2019). Based on sediments found within a core taken from the lake, before the damming, the area was likely a wetland, possibly a cypress (*Taxodium distichum*) swamp indicated by the peat-like sediments in the core (Balascio et al., 2019). Previous studies of the Coastal Plain have characterized these pre-milldam streams to have had a large and shallow floodplain, therefore, to have been slow-moving (Walter and

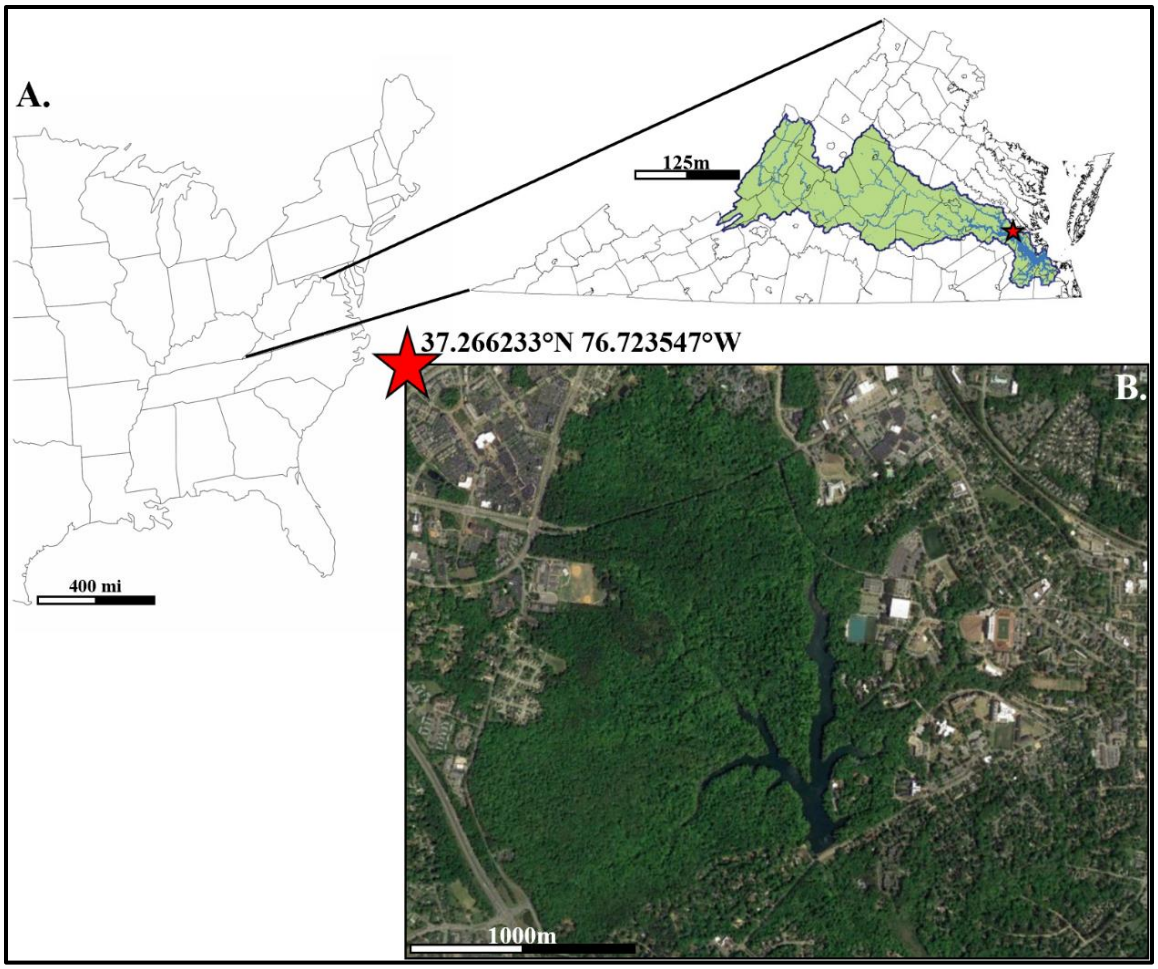

Figure 2: A) Location of Virginia on the United States east coast. Shaded in green is the James River drainage basin which includes Williamsburg, VA, marked on the map with the red star. B) Satellite view of Lake Matoaka (center) and the surrounding College Woods including the William & Mary campus on the right portion of the image (via Google Earth).

Merritts, 2008). Once dammed in 1700, the sedimentation rate remained relatively constant, especially following 1907 when the city paved Jamestown road and enabled the dam to be permanent, preventing sedimentation fluctuation due to storm events (Balascio et al., 2019). These conditions provide a unique opportunity to have a high-resolution continuous three-hundred-year record.

Currently, a secondary growth forest dominated by oak (*Quercus spp.*), beech (*Fagus grandifolia*), maple (*Acer spp.*), and pine (*Pinus spp.*) surrounds the lake. The forest has undergone many floristic surveys over the last 50 years, providing a detailed record of the

vegetation growing within the area (Barans, 1974; Crouch, 1990; Kribel, 2003; Cyrus, 2016). The most mature trees are about 160 years old, but the majority are only 90 years old at most (Ware, 1970; Cyrus, 2016). Despite the age, the contemporary forest has limited understory due to the overgrazing of white-tailed deer (*Odocoileus virginianus*) in the area (Kribel et al., 2011). The exact use of the land before the forest currently remains unknown aside from property plats and descriptions of farms in the area (Monroe and Lewes, 2016). Based on a study by Orwig and Abrams (1993), most forests in the Virginia Coastal Plain have originated from three potential scenarios. Pine dominated softwood forests often originate from abandoned agricultural fields and often date back to the early 20th century in age. Oak dominated forests have resulted from the succession of logging stands and often age back to the 19th century. The final group is the undisturbed forest (since the 19th century) which is also oak-dominated but lack fire regimes, have a significant amount of understory trees, and a lack of tall oaks. The fact that oak forests can be indicators for disturbed land, as well as pre-settlement forests, seems contradictory, but it potentially indicates the presence of fire regimes before human involvement (Abrams, 1992). The disturbances caused by natural fire regimes in the area maintained the dominance of oaks in the region. Once humans arrived, the disturbances continued despite the fires no longer occurring, maintaining the dominance of oaks species in the forests of Virginia. The College Woods is mostly a homologous mixture of tree genera, but there are patches of pine forest within the surrounding oak-dominated forest. This supports the notion that the woods have been host to a variety of human activities since the creation of the lake, including both logging and agriculture. However, the specific timeline of these events is not known and would provide valuable insight towards forest regeneration timing as well as the impact on plant diversity.

Phytoliths: Formation

Lake Matoaka's high-resolution sediment record proves to be ideal for identifying these kinds of small-scale events such as forest regeneration. A 2019 study by Balascio et al. on a core from the deep lake portion of Matoaka was able to calculate the relationship between age and core depth along with the sedimentation rate at different depths within the core (**Figure 3**). Using the fine chronology resulting from their study along with the mass accumulation rates at different depths, I was able to temporally evaluate the developed phytolith assemblages (Aleman et al., 2013). A range of plants create phytoliths, and the forms created are redundant and diverse by individual plant, but they are most abundant and distinct in the Poaceae family. Despite this uneven phytolith production rate, these proxies can still provide meaningful insights into the vegetation dynamics in a given area.

Plants create phytoliths through the uptake of amorphous silica in gel form from the soil or water (Piperno, 2006). Therefore, factors that influence silica availability affect phytolith production. Ideal conditions for phytolith preservation are low non-alkaline pH (<8, optimally 3) environments with low iron and aluminum oxides. Organic compounds in some plants increase silica stability (Gocke et al., 2013). Acidic soils feature a slower rate of silica dissolution, therefore preserving phytolith assemblages for a longer period. Phytoliths (as amorphous silica bodies) represent an important source of silica in soil, an element that is essential for optimal plant growth, and vegetation cover dominated in plants with passive silica transport (like softwood trees such as *Pinus spp*.), will result in greater rates of reabsorption (Ma and Yamaji, 2006; Cabanes et al. 2011). Despite the disadvantages of an iron and aluminum oxides-rich environment for phytolith formation, these elements can result in higher preservation following

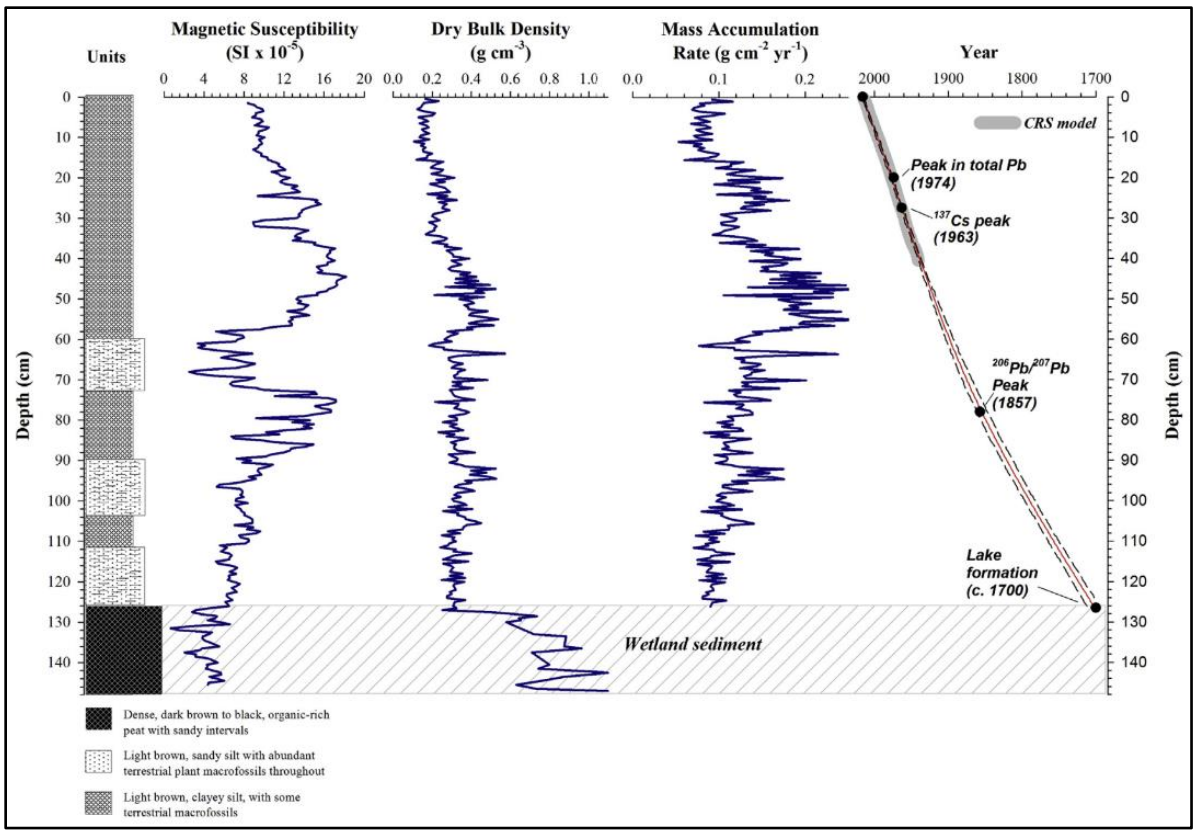

Figure 3: Data extracted from the Lake Matoaka core. Various depths have been correlated to a corresponding age and have also had sedimentation rates calculated throughout the age of the lake. These rates can be used when analyzing phytoliths to estimate accumulation rates throughout the lake's existence (Balascio et al., 2019).

deposition due to the chances of bonding with these microfossils (Piperno, 2006). The coastal plain of Virginia consists of Pliocene marine sediments with marine fossil formations. Within Lake Matoaka's drainage basin are the Yorktown and Bacon's Castle formations. These formations consist of marine fossils, the majority of which are calcium carbonate bivalve shells (Mixon et al., 1989). The calcium carbonate raises the pH of Lake Matoaka decreasing the probability of phytolith preservation. However, the soil in the College Woods is high in iron and aluminum oxides. Therefore, the sediments within the lake possess a marginally higher probability of containing *insitu* phytolith assemblages despite the higher pH values.

Methods

To properly determine the vegetative history of the College Woods, I approached the research in three parts: 1) the modern vegetation, 2) the modern soil, and 3) the sediment core. Due to no prior phytolith research within the College Woods, I developed a phytolith reference collection from fresh plant material and herbarium specimens to compare with the modern phytolith assemblage derived from the soils, as well as the historic lake sediment phytolith assemblage. All three outlined components of the research each consisted of a field component for specimen collection and a lab component for phytolith extraction.

Modern Vegetation

I assessed the modern vegetation of the College Woods using a vegetation survey by Kribel (2003). Kribel (2003) established 20 vegetation plots and performed a presence-absence count of flora within each plot. We used the data from the plots to compile the common taxa within the College Woods. Common taxa were denoted as being present in 20% or more of the vegetation plots surveyed (Preston, 1948). We then applied tier levels from Piperno (2006) to the

Table 1: Ubiquity values for common phytolith producing taxa of the College Woods

Tier	Family	Genus	Species	Plots Present	Ubiquity (%)
1	Cyperaceae	Carex	*spp*	19	95
2	Fagaceae	Fagus	*grandifolia*	19	95
2	Cupressaceae	Juniperus	*virginiana*	18	90
1	Magnoliaceae	Liriodendron	*tulipifera*	17	85
1	Magnoliaceae	Magnolia	*grandifolia*	16	80
2	Pinaceae	Pinus	*virginiana*	14	70
2	Fagaceae	Quercus	*alba*	14	70
2	Fagaceae	Quercus	*velutina*	13	65
2	Fagaceae	Quercus	*rubra*	11	55
2	Fagaceae	Quercus	*falcata*	6	30
2	Fagaceae	Quercus	*nigra*	5	25
2	Fagaceae	Quercus	*phellos*	4	20
2	Fagaceae	Quercus	*coccinea*	4	20
2	Fagaceae	Quercus	*michauxii*	4	20

common taxa to determine the common phytolith producing taxa within the College Woods. I chose to only use taxa denoted as tier 1 or 2, as these two tiers demarcate taxa (by family) that produce distinct and recognizable phytolith morphotypes. **Table 1** represents the most ubiquitous phytolith producing taxa from the vegetation plots. Note that I did not include *Carex spp.* in the modern vegetation analysis due to a lack of specimens observed during my collections in the College Woods and existing literature documenting the phytolith morphotypes (Piperno 2006). In addition to the vegetation with ubiquity higher than 20%, taxa belonging to the Poaceae family were added to the list of phytolith producing taxa due to their vastly higher percentages of phytolith production (Piperno, 2006). I also added pawpaw (*Asimina triloba*) to the modern vegetation due to its high abundance as understory foliage in the Williamsburg area as well as its designation as a tier 1 specimen due to its classification within Annonaceae (Piperno, 2006). Additionally, despite having a ubiquity of 30% (**Table 1**), I did not process a specimen of *Quercus falcata* due to it having already been used in a reference collection held by the Archeology department of the Colonial Williamsburg Foundation. The collection contains images of the different phytolith morphotypes extracted from the plant material.

Using the list of common taxa, I collected leaf material for all specimens in addition to woody material for the bark-producing taxa during the months of June and July of Summer 2020. For taxa unable to be located, the William & Mary Herbarium (WILLI) provided plant material from duplicate specimens (**Appendix C**). The Colonial Williamsburg Foundation Archeology Lab also provided access to their phytolith reference collection. Collected specimens were placed in a drying oven at 50˚C for at least 24 hours to prepare for phytolith extraction. Once the material was dried, we followed the phytolith extraction protocols of and Parr et al. (2001). The organic matter was removed by an initial dry-ashing at 500˚C followed by carbonate removal

with (10%) HCL, and subsequent organic matter removal with (15%) H_2O_2 treatments. The resulting extracted material was then mounted (200 µg) on a slide using Entellan®. The pellet weight of each specimen was then compared to other specimens to identify variations in the amount of material produced by the different taxa. A future assessment of the phytoliths produced per gram for each taxon will represent the true phytolith yield of each species. With this data, I was able to determine which taxa would be more prevalent within the phytolith assemblage of the College Woods. The information was also used to determine which species produced material at an expected level of 200mg and which did not.

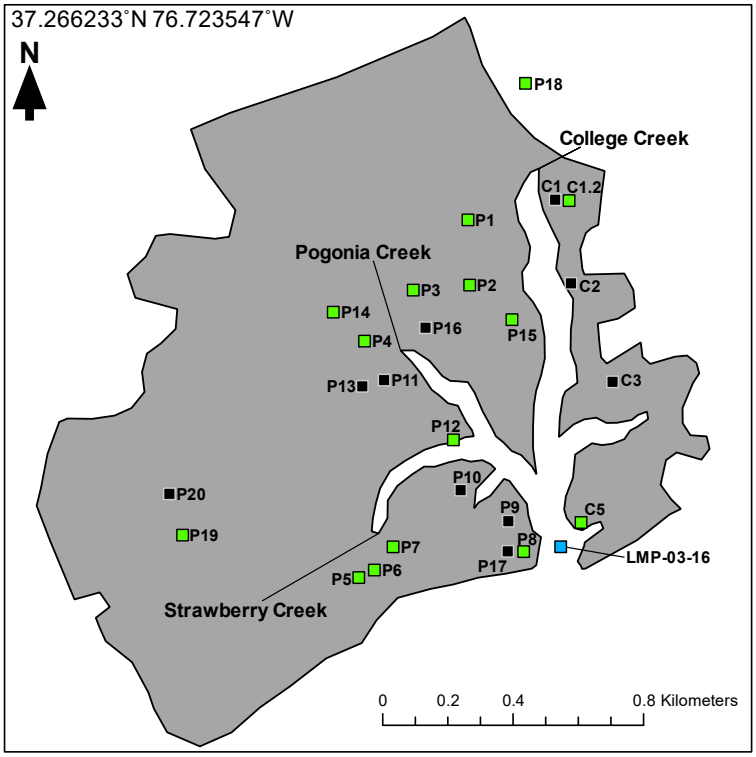

Figure 4: Map of the College Woods (grey). The five easternmost (left of the main College Creek drainage) points are the locations created in this study. The 20 additional points are the plots established in Kribel (2003) Green points represent samples processed and counted, black points represent samples collected but not processed. Blue point represents lake sediment core LMP-03-16 from Balascio et al. (2019). The mouths of each creek are labeled. Note Pogonia Creek in this study represents Berkeley stream, Swan fork, and Aralia ravine (Crouch, 1990).

Modern Soil

The lacustrine sediments reflect runoff from the surrounding drainages. As a result, I conducted a systematic field collection of the modern soil surface during the months of July and August 2020, taking care to sample representatively **(Figure 4**). I collected 25 soil samples of the upper A horizon from all 20 vegetation plots established in Kribel (2003). Additionally, I

randomly chose five plots on the eastern side of the College Woods. This eastern side is adjacent to the William & Mary campus while the rest of the College Woods is distinctly separate from the campus.

From the 25 samples, I selected 15 samples, that properly covered the entire College Woods area. I first measured the pH of each sample to account for the role of pH in the dissolution of phytoliths. I weighed 15g of humid soil into a cup and mixed it with water to form a 50-50 water to soil slurry. Samples were left to sit for 30 minutes as per the Kellogg Biological Station of Michigan State University's protocol. Following the thirty minutes, pH was measured using a Thermo Scientific™ Orion™ 4-Star Plus pH/ISE Benchtop Multiparameter Meter and recorded to the hundredth of a pH. Soil samples were then dried at 50˚C to remove any moisture from within the samples then 5g of material was sieved used a 250µm mesh sieve. Following this, I followed the phytolith extraction protocol from Rosen and Weiner (1994). First, carbonates were removed with (10%) HCl, the samples were deflocculated with Calgon, organic matter was burned off in a muffle furnace at 500 ˚C, and then the material was separated via heavy liquid (sodium polytungstate). The resulting extracted material was mounted (200 µg) with an Entellan medium on a slide with 24X24 slide covers. I counted the phytoliths on the slides under 400X magnification on a compound, transmitted, polarizing light microscope following the protocol of Albert and Weiner (2001). Each slide was counted, noting the abundances of the different morphotypes following the latest ICPN morphotype classification 2020. Slides were counted to 300 single cells and 100 multicells to calculate the acid-soluble fraction – or the number of phytoliths per gram. Morphotypes were classified as dicot and monocot morphotypes, as these plant taxa coarsely define grassland and woodland landscapes (Alexandre et al., 1997; Delhon et al., 2003). Note, the use of the term dicot in this study

includes both eudicots as well as magnoliids. For the construction of the dicot:monocot ratios, I also included gymnosperm morphotypes into the dicot designation as they aid in the intent to use the ratio to reflect the proportion of forest vegetation. In the course of counting, I qualitatively assessed the biases of preservation in the phytolith record during the deposition and subsequent taphonomy within the sediments by documenting the incidence of dissolution pits (Madella and Lancelotti, 2012). A ratio of dicot abundance in comparison to monocot abundance was derived (n of dicot morphotypes / (Σ n of dicots + n of monocots) for each sample to create a summarized value for the modern woodland. This value enables ease of comparison with the paleoecological record in the lake core.

In total, I selected nine variables to use as predictors for the phytolith assemblage variation: total phytoliths per gram, dicot:monocot ratio, multicell:singlecell ratio, pH, slope, elevation, surrounding vegetation, creek watershed, and land type. I determined elevation, slope, and land type using a digital terrain model calculated using 1-meter resolution LIDAR data processed within ESRI's ArcGIS pro. I used Shapiro–Wilk tests to determine the normality of each of the chosen variables, then performed two-tailed t-tests, Kruskal-Wallis tests, and Wilcoxon singed-rank tests to determine whether any of the variables were influencing one another.

Lake Sediments

Five samples, four encompassing 31.5 cm of sedimentation via the pinch method (representing 50 years) plus the pre-lake sample, were collected and processed using a modified protocol for phytolith extraction from lake sediments based on Aleman et al. (2013) and Li et al. (2019). I first measured the pH of each of the 5 samples using the same protocol outlined for the modern soil. Following this, the samples were dried and weighed out to ~10g before

deflocculation with a 5% Calgon solution. 30% H_2O_2 was added to the sediments and allowed to react for 12-24 hours or until the reaction ended to remove organic matter from the sediments. In cases where there were high concentrations of organics within the sediments, a 65% solution of HNO_3 was added before the H_2O_2. Following this step, carbonates were removed from the sediments using 15% HCl. A second round of deflocculation is done identically to the Rosen and Weiner (1994) protocol. Finally, SPT (sodium polytungstate) with a density of 2.3g/ml was added to the samples and centrifuged to separate the phytoliths from the remaining sediment. The remaining material was dried and mounted (200 µg) with an Entellan medium on a slide with 24X24 slide covers. I then observed the slides under 400X magnification with a compound, transmitted light microscope. Phytoliths were counted in the same method as described in the modern soil section above.

I analyzed the lake sediments based on four variables: total phytoliths per gram, dicot:monocot ratio, multicell:singlecell ratio, and pH. I compared the values for each variable at the five depths to the average value of the modern soil phytolith assemblage by determining the difference in standard deviations.

PCA

I opted to use a principal component analysis (PCA) to compare the modern phytolith assemblage to the lake phytolith assemblages. The PCA used four variables: total phytoliths per gram, dicot:monocot ratio, multicell:singlecell ratio, and pH. Three PCA's were calculated using the R studio version 3.6.3's 'factoextra' program: 1) A PCA of the four variables using values from the fifteen modern plots to determine which variables are more important in explaining the variation between the plots. 2) A PCA of the four variables with modern plot values and grouped by creek watershed. The values from the lake samples were plotted on top to determine the fit of

the lake samples in terms of creek watershed and to determine whether the lake environment reflected any of the modern creek environments. 3) The same PCA and the previous, but the points were grouped by surrounding vegetation to determine whether or not the lake phytolith assemblages fit within the modern vegetative communities or belong to communities no longer present within the modern College Woods.

Results

Modern Vegetation

Based on the amount of material extracted from each taxon using an initial weight of 100mg, 200mg, or 500mg, three categories were created: I) specimens that produced no material, II) specimens that produced less material than expected based on the protocol from Parr et al. (2001), and III) specimens that produced material at the level expected. The specimens in category I produced no mountable material from initial weights of 200mg, 500mg, or 100mg in the case of Poaceae (**Table 2**). The specimens in category II produced no material at 200mg but did produce enough mountable material at 500mg (**Table 3**). Specimens in category III produced mountable material from 200mg or 100mg in the case of Poaceae (**Table 4**). Three out of the four specimens that did not produce material came from bark samples. The other specimen came from leaf material of a Poaceae identified as part of the tribe Andropogoneae. All samples of bark required 500mg of raw material to be processed. Excluding the Andropogoneae specimen, all Poaceae required only 100mg of raw material for successful extraction. Oaks, as the most common genus within the reference collection, varied by species with some producing material

more readily than others. During extraction, one batch of specimens underwent an error in which the order of carbonate removal and organics removal were swapped. These specimens are shown shaded in grey (**Table 2**, **3**, and **4**)**.**

Table 2
College Woods common taxa specimens producing no viable phytolith material (Category I)

Tier	Family	Genus	Species	Material Type
2	Cupressaceae	Juniperus	*virginiana*	bark
2	Fagaceae	Quercus	*alba*	bark
2	Pinaceae	Pinus	*virginiana*	bark
1	Poaceae	Andropogoneae	NULL	leaf

Table 3
College Woods common taxa specimens producing less viable phytolith material than expected (Category II)

Tier	Family	Genus	Species	Material Type
1	Annonaceae	Asimina	*triloba*	bark
1	Annonaceae	Asimina	*triloba*	leaf
2	Fagaceae	Fagus	*grandifolia*	bark
2	Fagaceae	Quercus	*coccinea*	bark
2	Fagaceae	Quercus	*coccinea*	leaf
2	Fagaceae	Quercus	*michauxii*	bark
2	Fagaceae	Quercus	*nigra*	bark
2	Fagaceae	Quercus	*nigra*	leaf
2	Fagaceae	Quercus	*phellos*	bark
2	Fagaceae	Quercus	*rubra*	bark
2	Fagaceae	Quercus	*rubra*	leaf
2	Fagaceae	Quercus	*velutina*	bark
2	Fagaceae	Quercus	*velutina*	leaf
1	Magnoliaceae	Liriodendron	*tulipfera*	leaf
1	Magnoliaceae	Magnolia	*grandiflora*	bark

Table 4
College Woods common taxa specimens producing the expected level of viable phytolith material (Category III)

Tier	Family	Genus	Species	Material Type
2	Cupressaceae	Juniperus	*virginiana*	leaf
2	Fagaceae	Fagus	*grandifolia*	leaf
2	Fagaceae	Quercus	*alba*	leaf
2	Fagaceae	Quercus	*michauxii*	leaf
2	Fagaceae	Quercus	*phellos*	leaf
1	Magnoliaceae	Magnolia	*grandiflora*	leaf
2	Pinaceae	Pinus	*virginiana*	leaf
1	Poaceae	Brachyelytrum	*erectum*	leaf
1	Poaceae	Dicanthelium	NULL	leaf
1	Poaceae	Microstegium	*vimineum*	leaf
1	Poaceae	NULL	NULL	leaf

Modern Soil

All 15 of the sampled plots produced enough material to meet the 300 singlecell counting threshold **(Figure 5**). None of the 15 plots produced the 100 multicell morphotypes required to meet the threshold for counting multicell morphotypes. Plots were analyzed using the calculated single cells per gram, dicot:monocot ratio, multicell:singlecell ratio, pH, elevation, and slope values. Based on these collected values for each plot and the counted phytolith morphotypes, there exists a high degree of variation between the different plots (**Table 5**). The standard deviation of all of the counting fields is larger than the averages, pointing to a large variability within the data. The calculated dicot:monocot ratio for each of the plots is less variable compared to the other phytolith metrics, with a standard deviation of 0.07 compared to an average value of 0.25. Dividing the plots based on the three western tributaries of Lake Matoaka, Pogonia, College, and Strawberry Creek, as well as dividing plots based on highland and lowland, present different distributions for each of the measured variables (**Figure 6**). No plots were sampled from within the watershed of Crim Dell creek, the main drainage of the William & Mary campus. One plot, Campus 5, is not positioned within the three major tributaries of the lake (C5 in **Figure 4**). Its location washes directly into the lake, which I categorized as College creek due to the lake forming from the damming of College Creek. I performed all statistical tests including

Table 5
Summary statistics for the chosen variables measured within each plot; averages displayed with standard error

Category	Average	Standard deviation	Minimum	Maximum
Multi cell/gram	7.00 ± 2.06	7.99	0	25
Single cell/gram	1616.53 ± 521.62	2020.21	185	8322
Dicot:Monocot ratio	0.25 ± 0.02	0.07	0.15	0.40
Multi cell:Single cell ratio	0.0046 ± 0.0009	0.0034	0.0000	0.0091
pH	5.54 ± 0.19	0.75	4.90	7.61
Elevation (m)	18.13 ± 1.75	6.78	8.23	31.35
Slope (°)	6.47 ± 1.44	5.57	1.07	20.43

Campus 5 categorized as College creek as well as a set excluding Campus 5. There was no significant difference between the dataset containing Campus 5 as belonging to College creek and the dataset excluding it when analyzing the impact of the watershed on the data using Kruskal-Wallis tests. I also analyzed the data including and excluding Plot 14, the outlier in terms of singlecell phytoliths per gram. There was no significant difference between the dataset including plot 14 and the data set excluding it. I determined the surrounding vegetation of each plot using the presence/absence data collected in Kribel (2003). Plots with observed hardwoods (Fagaceae, Juglandaceae, etc) and softwoods (Pinaceae) were categorized as mixed. Plots with only hardwood trees were classified as hardwood. Plots with high amounts of aquatics or

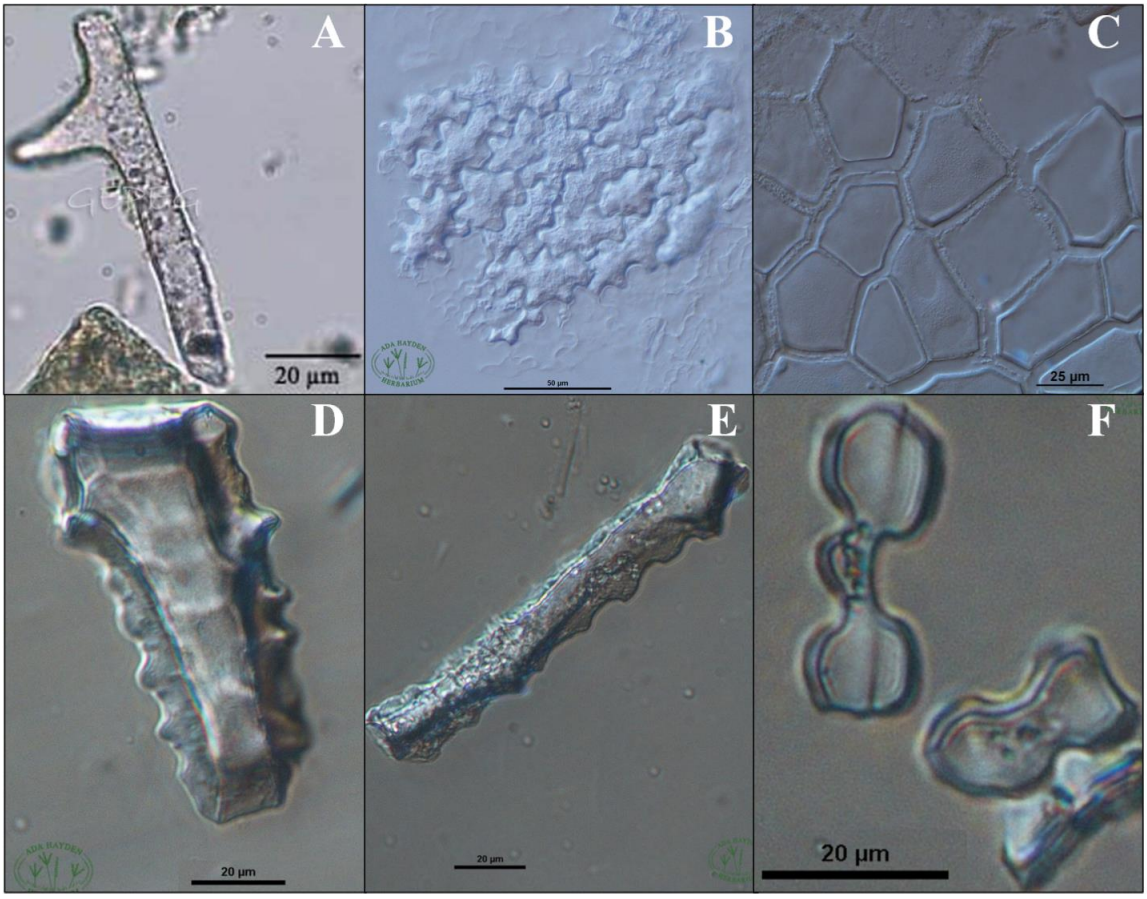

Figure 5: Images of single cell phytolith morphotypes: A-C represent dicot morphotypes; D-F represent monocot morphotypes. A) Sclerid phytolith; B) Jigsaw multicell from *Fagus grandifolia*; C) Sheet multitier from *Quercus alba*; D) Crenate phytolith from *Brachyeltrum erectum*; E) Long cell phytolith from *B. erectum*; F) Bilobate shortcells from *B. erectum*. Images via PhytCore.

wetland vegetation (Cyperaceae) were classified as wetlands. Finally, plots with low tree counts and high shrub (Ericaceae) and grass (Poaceae) were classified as shrubland. I categorized the campus side plots using the observed vegetation within proximity to the location the sample was collected. In total there are two wetland plots, two shrubland plots, seven mixed plots, and four hardwood plots.

I tested all of the variables for normality using Shapiro–Wilk tests and found that only the dicot:monocot ratios and elevations have normal distributions (p-value > 0.05). I categorized plots into highland (> 20m a.s.l.) and lowland (≤20m a.s.l.) to be used in two-tailed analyses of the influence of elevation on the variables. Using Wilcoxon singed-rank tests, I found none of the non-parametric variables to be influenced by the elevation of the plots (two-tailed t-test), I evaluated the influence of elevation on the dicot:monocot ratio and found there to be no relation (p-value > 0.05). The influence of surrounding vegetation and creek watershed was determined using Kruskal-Wallis tests. None of the variables were influenced by either surrounding vegetation or creek watershed (p-value > 0.05). Overall, none of the statistical analyses performed produced significant results using the chosen variables.

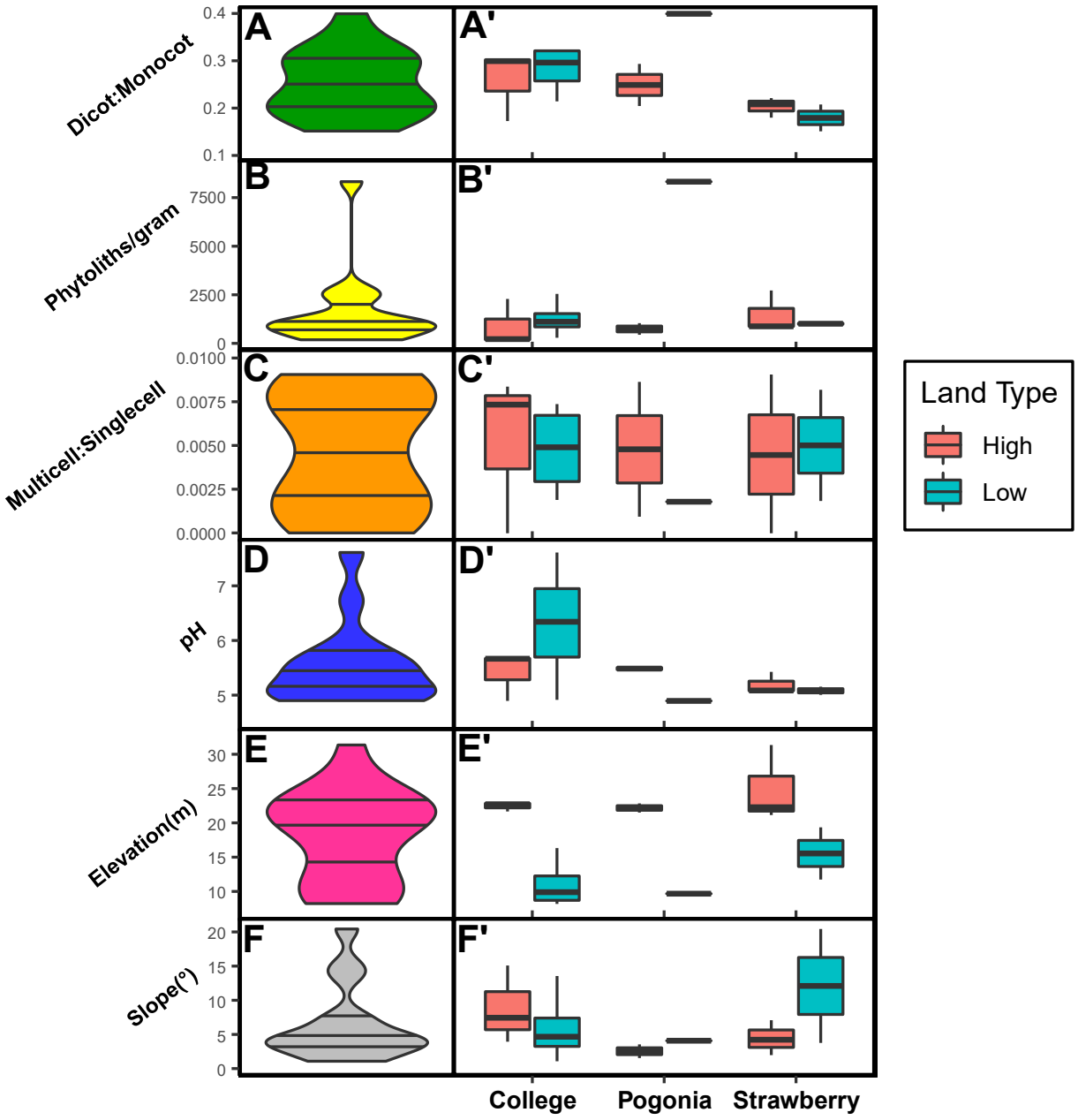

Figure 6: Violin plot and box plot of the distribution of data from each of the 15 sampled plots in the College Woods. *A-F*) Violin plots of the measured data, black lines divide the data into four quartiles. Increases in width represent higher densities of data points. *A'-F'*) Boxplots of the measured data grouped based on the watershed the plot resides within and the elevation of the plot. Highland plots are >21 meters above sea level and lowland plots are ≤ 20 meters above sea level. *A,A'*) Dicot:monocot ratio, *B,B'*) Total number of singlecell phytoliths within a gram of sediment, *C,C'*) Ratio of multicell morphotypes to singlecell, *D,D'*) Soil pH at each plot, *E,E'*) Elevation measured at each plot, *F,F'*) Degree of slope at each of the sampled plots.

Lake Sediment

Overall, all samples from the lake core produced the 300 single-cell phytoliths necessary for statistical analysis, while none produced the 100 multi-cells. All of the chosen variables display an abrupt transition between the pre-1700 samples and the 1700-1810 sample (**Figure 7**). Following the 1700-1810 sample, the values stabilize between the different depths. The only exception to this is the pH which remains stable between 6.71 and 7.00. I compared the values at each depth within the lake core to the mean value of that variable for the modern soil by using standard deviations of the modern soil (**Table 6**). Only two values, the phytolith/gram of 94.5-126.0cm and the dicot:monocot ratio of 126.0-150.0 are > 2σ from the mean, indicating an increased likelihood that these two values belong to a different population. Overall, the values from the lake vary slightly from the modern soil, but only the two values listed above are significantly different. The modern lake sediment, 0-31.5cm, slightly varies from the modern soil phytolith assemblage. For example, the dicot:monocot ratio of the modern lake sediment is 0.33 while the average modern soil, including the Pogonia Creek outlier, is 0.25. Despite the difference, the 0.33 falls within the natural variation of the modern soil.

Table 6: Table of nσ from modern sediment mean for the variables at each lake depth; shaded values represent > 2σ from the mean

Depth (cm)	Phytolith/gram	Dicot:Monocot	Multicell:Singlecell	pH
0.0-31.5	0.97	1.29	-1.11	1.67
31.5-63.0	1.70	0.71	-0.41	1.56
63.0-94.5	1.74	-0.43	-1.07	1.85
94.5-126.0	7.52	-0.14	-0.68	1.95
126.0-150.0	-0.25	2.57	-0.56	1.60

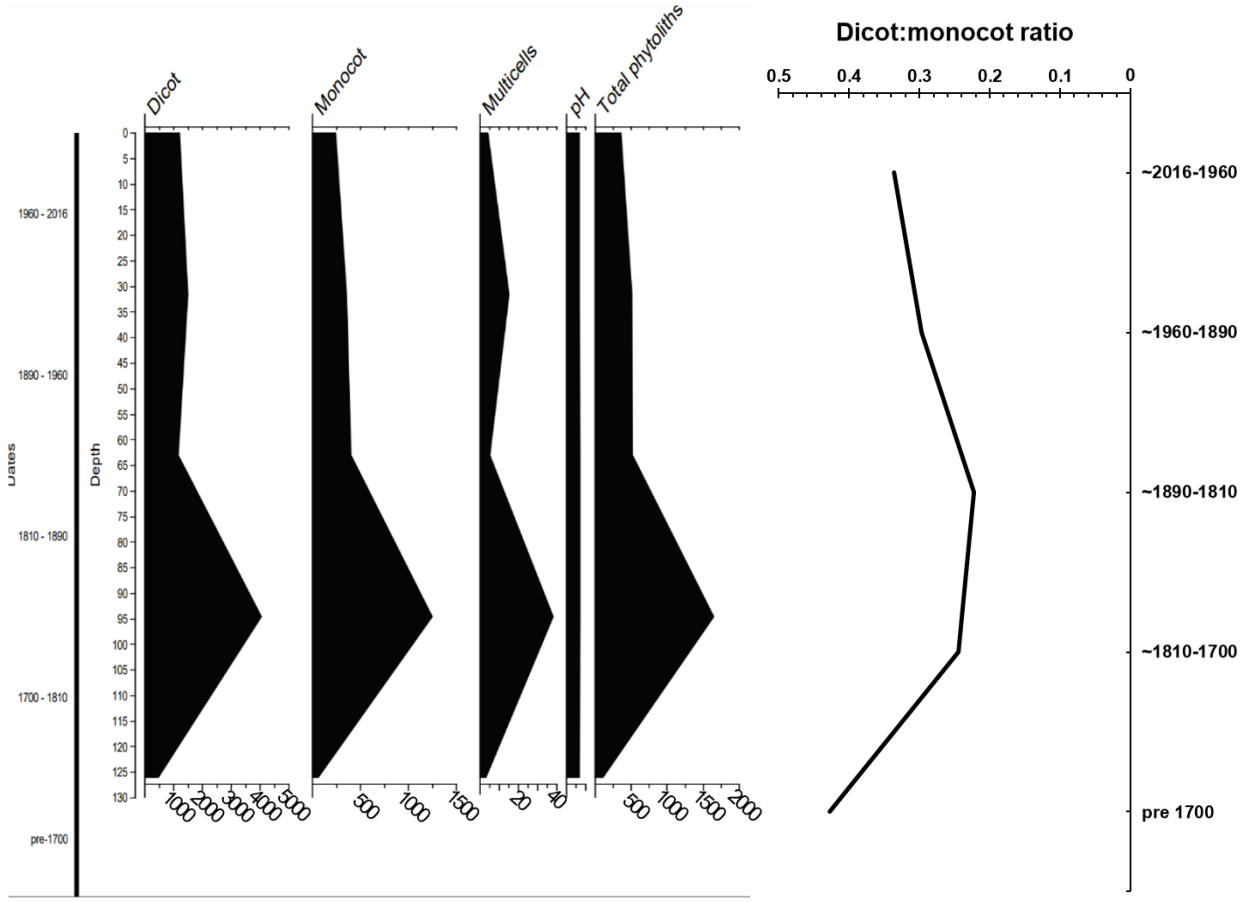

Figure 7: Graph of the changes in dicot and monocot phytoliths/gram, multicell:singlecell ratio, pH, total phytoliths/gram, and dicot:monocot ratio. Note the abrupt transition between pre 1700 and 1700 as a result of the damming of Lake Matoaka. Variable values transformed for visual comparison.

PCA

All four variables – total phytoliths per gram, dicot:monocot ratio, multicell:singlecell ratio, and pH – influence the PCA (**Figure 8**). Together, the two eigenvalues of the PCA explained 71.9%. High values of phytoliths per gram and the dicot:monocot ratio were the most significant variables in PCA1 (42.1%) while high pH values were the most significant variable for negative values of PCA1. PCA2 (29.8%) was defined by high values of pH and dicot:monocot ratio, while high multicell:singlecell ratio contributed the least of all the variables yet had the strongest association within PCA2. High phytoliths per gram values are associated with negative values on PCA2. The results of grouping the plots based on surrounding vegetation

show a high degree of overlap between the four vegetation types – hardwood, mixed, shrub, and wetland. Hardwood, mixed, and shrub overlap with one another. Shrubbery communities, while overlapping with hardwood and mixed vegetative communities, are clustered on the positive side of PCA1 suggesting the primary variation is explained by high values of the total phytoliths per gram and dicot:monocot ratio. The only vegetative community to not overlap with the other three is the wetland group. The wetland varies primarily along PCA2 with some variation in the negative PCA1. This trend directly follows the pH variance, indicating a strong association between the pH of the plot and whether or not the plot is a wetland.

The PCA grouped by creek watershed shows an even higher degree of overlap between the three creeks (**Figure 8**). Pogonia creek has the largest grouping, suggesting a higher degree of variation within this creek watershed as opposed to the other two on the tested variables.

The addition of the lake samples on the two PCA plots highlights the degree of separation between the modern phytolith assemblages and the lake. In terms of the vegetative groupings, only sample 18 – c.1810-1890 – fits within the modern data, matching with the mixed vegetative community. Samples 16 and 17, corresponding with the vegetation from 1890 – present, fall closer to the shrub and wetland types but do not directly match either. Samples 1, 1700-1810, and 20, pre-1700, are strong outliers in the data with sample 20 varying along PCA2, indicating a distinction based on multicell:singlecell ratio and dicot:monocot ratio values and sample 19 varying along PCA1 indicating a strong influence from total phytoliths per gram. Grouping the points based on creek watershed, show samples 16-19 fall within the modern creek watersheds. Only sample 20 is a direct outlier, not fitting any of the modern creek watersheds. Overall, samples 19 and 20 are the least similar to the modern phytolith assemblages of the College Woods.

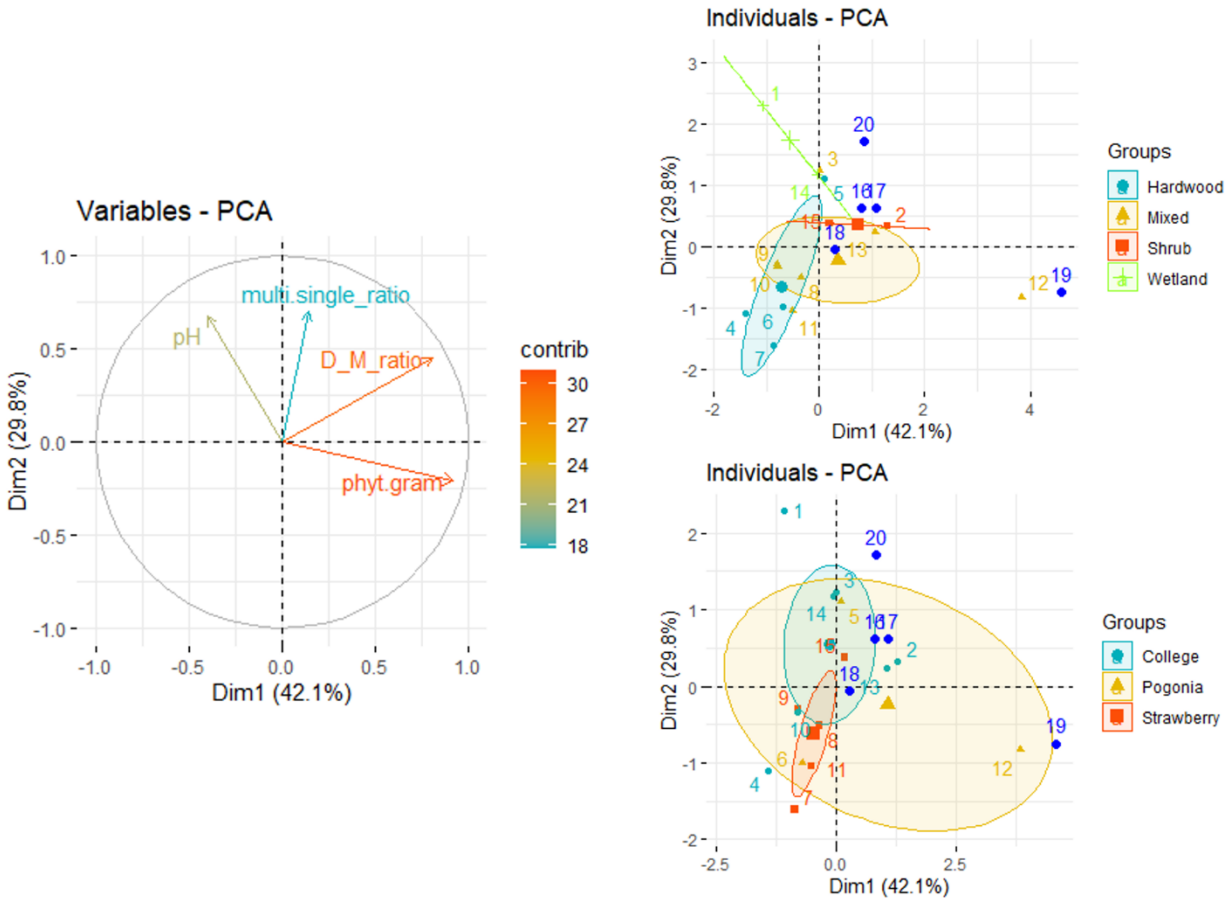

Figure 8: PCA of dicot:monocot ratio, phytolith/gram, multicell:singlecell, and pH; A) PCA score plot of the modern soil phytolith assemblage; B) PCA of the modern soil grouped by vegetative community including the position of lake samples; C) PCA of the modern soil grouped by the creek watershed with the lake samples included

Discussion

Modern Vegetation

Within each tier, there exists a degree of variability between taxa. The tier of a taxon does not reliably predict the yield of the material. I did not count morphotypes of any of the specimens, instead, all interpretations of yield are based on the yield of at least 200µm of material to mount. Some Tier 1 specimens, such as *Magnolia grandiflora*, required only 200mg of raw material while others, such as *Asimina triloba*, required 500mg. The same is true for specimens within Tier 2, with different families producing different results. These yields are subject to a degree of skepticism as all of the material came from a single specimen. The

phytolith yield varies between individuals within a species, even between high yield taxa like Poaceae (Kealhofer et al., 2015). Piperno (2006) describes Tier 1 classifications as: "Families where production is usually high, phytoliths specific to family are common, and subfamily and genus specific forms occur, sometimes widely in the family" and Tier 2 classifications as "families where production may not be high in many species studied but where family and genus specific forms or forms diagnostic of specific growth habitat occur." The material extracted may contain distinct and characteristic phytolith morphotypes, fitting with the given definitions. The data suggests however that within and between specific families, the actual phytolith yield may vary. These findings could suggest that phytolith yield is more dependent on the specific taxa. This is in addition to the inherent variation between individual specimens with factors like the age of the plant and environmental conditions influencing the phytolith production (Madella et al., 2009). Piperno's classifications may broadly characterize the phytolith production of families, but between genera within a family and between species within a genus, the degree of phytolith production varies regardless of tier classification. In addition, the tier of a species also does not seem to apply to the production of phytoliths within woody material. It has been shown that both bark and wood produce phytoliths, with bark producing recognizable morphotypes. The yields of the woody material are much lower than other plant materials (Tsartsidou et al., 2007; Collura and Neumann, 2015). My results support these previous studies, with all of the bark specimens requiring 500mg of material to produce a viable yield, regardless of tier, with some specimens lacking a yield entirely. This likely translates to a low abundance of bark phytolith morphotypes within the modern soil assemblage and the need for more work to be done on determining the influence of taxa on the production of phytoliths within bark and wood (Albert et al., 2006).

As with previous study results, grasses dominate the phytolith assemblages due to the high rate of production (Stromberg, 2002; Lu and Liu, 2003; Piperno, 2006). Despite Poaceae being less common in the College Woods, the majority of the counted phytoliths come from monocots, and specifically grasses. Dicot-derived phytoliths make up a small percentage of phytoliths due to the decreased production. Oaks are the richest genera of dicots within the area and their designation as Tier 2 implies they produce distinct morphotypes. Beech (*F. grandifolia*), which shares the same ubiquity as oaks (*Quercus spp.*) in the woods, is also classified as tier 2, indicating that most dicot morphotypes came from these two taxa. The exception to the dominance of Poaceae in the phytolith record seems to be the Andropogoneae specimen collected. Due to past studies of Poaceae phytolith production, including studies of Andropogoneae (Inoue et al., 2015), the lack of a yield is likely due to two possible errors:

1) The specimen may have been misidentified as a member of the tribe Andropogoneae. This scenario is the least likely to have had an impact because, based on morphology, the specimen was keyed to Poaceae first. This means even if the tribe designation was incorrect, the specimen still belonged to Poaceae and the phytolith yield of it should have been similar to other Poaceae specimens.

2) A possible error in the extraction protocol may have caused the lack of a yield. An acid is used to dissolve the carbonates within the material, the acidic environment increases the efficiency of H_2O_2 for dissolving the organic matter within the specimen (Aleman et al., 2013). When done out of order, the H_2O_2 does not react as efficiently and may not break down all of the organic matter. During the extraction, the Andropogoneae specimen was a part of the batch of specimens where H_2O_2 was mistakenly added before the HCl (**Table 2**). Despite this, 11 other specimens were processed in the same batch with a majority yielding mountable material,

including three other Poaceae specimens. It's unclear why there would be such a discrepancy between the yields of the different specimens. The specimen may have grown in a silica poor environment, but previous studies have observed silica poor environments to lower the yield of phytolith production in Poaceae rather than prevent production entirely (Marxen et al., 2016; Nawaz et al., 2019; Sun et al., 2019). More samples of Andropogoneae need to be tested to determine the true yield of the taxon.

The variation in the yield of material from different oak species could be due to an error during extraction or a natural phenomenon:

1) Tier 2 classified taxa are described as varying in phytolith production between species within a family (Piperno, 2006). It is possible this phenomenon is being observed within the oaks common to the College Woods. Three oak species: *Quercus alba*, *Q. michauxii*, and *Q. phellos*, produced the expected amount of material from their leaf material. Four species: *Q. coccinea*, *Q. nigra*, and *Q. velutina*, produced less material than expected from their leaves. These results point to a near 50:50 split between oak species producing the expected amount or less. Natural variation can explain this observed phenomenon, supporting the Tier 2 classification given to oaks in Fagaceae. However, more extensive testing is needed to definitively prove whether the cause of the variations is natural. Previous studies have identified different soil and habitat preferences for different oak species, which may influence the taxon's phytolith production (Farrell and Ware, 1991). *Q. michauxii* and *Q. coccinea* both prefer low calcium and pH soils, the same conditions that best preserve phytoliths in the soil (Carey 1992a, 2013; Piperno, 2006). This points to two possible outcomes: 1) higher chance of *Q. michauxii* and *Q. coccinea* phytolith morphotypes preserved in the soils around the specimen. 2) Lower phytolith production within *Q. michauxii* and *Q. coccinea* due to less dissolved silica available for uptake. My results

are inconclusive, with *Q. michauxii* producing the expected yield of phytoliths and *Q. coccinea* producing less than expected (**Table 3** and **4**). More samples need to be collected and tested to determine whether or not these soil preferences are influencing the phytolith yield of the two species. Two other species of oak – *Q. phellos* and *Q. velutina* – prefer more acidic soils as well (Farrell and Ware, 1991; Carey 1992b, 1992c). As with *Q. michauxii* and *Q. coccinea, Q. phellos* produced the expected yield of material while *Q. velutina* produced less than expected (**Table 3** and **4**). These results suggest more tests should be done on other species of oak as well as more specimens from the species mentioned in this study to understand the full scope of the variation in production within oak taxa. This would enable a better understanding of phytolith production within a genus as well as provide additional support to the tier designation by Piperno (2006).

2) Additional samples would also support whether or not the observed phenomenon between the oak species is due to an error during the extraction procedure. We processed *Q. michauxii, Q. phellos, Q. rubra,* and *Q. velutina* in the same batch as the Andropogoneae specimen (**Table 3** and **4**). The error in the procedure possibly triggered some of the oaks to not produce their true yield. However, for Andropogoneae, a Tier 1 specimen, there was no material produced, but in the case of oaks, which are designated as Tier 2 specimens, the yield dropped to producing less than expected. *Q. michauxii* produced the expected amount of material despite the protocol error. *Q. coccinea* and *Q. nigra* both produced less material than expected despite no error in the extraction protocol. Due to these inconsistencies, it is difficult to confidently assess the impact of the protocol error on the oak specimens' yield. This suggests that these observed variations may be more dependent on a separate factor such as the previously mentioned variation in taxa. Processing more samples of the different species would help clarify the true

yield of the different taxa and enable future studies to accurately assess the contribution of phytoliths into the environment by oak taxa.

3) The third possible cause for the variation in oak yields is related to the environmental conditions of the individual specimens. Each oak specimen was collected from a different location in Virginia (**Appendix C**). None of the oaks I sampled were within close proximity to one another. This is important because the amount of soluble silica in the soil has an impact on the phytolith production within the plant tissue (Piperno, 2006; Nawaz et al., 2019). If some of the oaks sampled were in low silica environments, then their yield would be less than expected. Plants are only able to generate phytoliths when there is free silica dissolved in the groundwater. For plants like Poaceae, silica is actively taken in to generate phytoliths, while in other plants, phytoliths are passively generated as a byproduct of silica uptake in water (Piperno, 2006; Nawaz et al., 2019). Oaks likely fall into the latter category, due to their position in Tier 2 and as a eudicot, but no research has been done in this area (Nawaz et al., 2019). The passive development of phytoliths would be more impacted by a low soluble silica content, as the plant does not have the mechanisms in place to extract silica in low concentrations. The oak specimens that produced less material than expected may have been collected in areas with a low concentration of soluble silica, contributing to their limited yield. This could be tested with more specimens collected from different locations and their yields compared to this batch to assess whether the phytolith production is consistent within the different species.

Overall, these results suggest that oaks, despite being the richest genus within the College Woods, likely do not contribute heavily to the modern phytolith assemblage. Their yield is low compared to other species and the production varies heavily between species. These results support previous research involving phytolith production in oaks and their unreliability in

producing diagnostic phytolith signatures (Bremond et al., 2004). *Fagus grandifolia* or American Beech, another genus within the Fagaceae family, likely contributes significantly more to the phytolith assemblage (Farmer et al., 2005). *F. grandifolia* is the most common species of tree within the College Woods when excluding Acer rubrum due to Sapindaceae not producing recognizable phytoliths (Piperno, 2006). *F. grandifolia* occurred in 95% of all of the samples plots within the College Woods, implying a near homogenous spread across the area (**Table 1**). My results show that *F. grandifolia* produced the expected amount of material from its leaves (**Table 4**). Past studies have also shown that *F. grandifolia* prefers less alkaline soils, tending to avoid limestone-rich soils (Coladonato, 1991). The preference of avoiding more basic soils may assist in the preservation of *F. grandifolia* phytoliths but more work needs to be done to conclusively identify any correlation. My results paired with the abundance of *F. grandifolia* within the College Woods suggest that it is likely the main contributor of dicot phytolith morphotypes within the modern assemblage with oaks and less common species contributing phytoliths dependent on the taxa nearby.

Modern Soil

Despite the variability of the collected data for each plot, the results of the statistical tests point to a homogenous distribution of phytolith assemblages within the College Woods. I found that none of the selected variables had any influence on the counted phytoliths within the plots. This could point to a possible external variable that was not chosen within this study. I selected common environmental variables that typically are important factors in influencing vegetation habitat preference: slope, pH, and elevation (Farrell and Ware, 1991). The lack of influence could be due to a lack of relief between the plots, with a range of ~23m (**Table 5**). It could also be from a lack of enough plot data. There are a total of twenty-five plots, five established by me

for this study and 20 by Kribel (2003), including the ten additional plots I did not opt to include in this study. Including the additional plots would increase the sample size and add to the confidence of the accuracy of the statistical tests I performed. It is also possible that a variable I did not study, such as soil type, has an important influence on phytolith production but I was unable to test this during my project. The insignificant results when assessing the impact of creek drainage on phytolith count within a plot adds to the conclusion of homogeneity within the woods. There was no relationship found between which tributary drainage the plot resided within and the phytolith assemblage at that plot. Despite previous floristic surveys of the College Woods identifying diverse communities of vegetation throughout the different watersheds, my results suggest that in terms of phytolith producing vegetation there is no detectable difference between the different tributaries. The same is true for the surrounding vegetation, despite the range of vegetation types at the different plots, the vegetation growing within the plots did not play a significant role in the observed variation of phytoliths at each plot. These results imply the phytolith assemblages do not vary based on elevation, pH, slope, surrounding vegetation, and creek in the communities surrounding Lake Matoaka. This homogeneity throughout the College Woods implies that sampling from anywhere within the College woods will produce an accurate representation of the phytolith signature of the whole area.

The dicot:monocot ratio, which I used as a proxy for the vegetation on the landscape, was not significantly influenced by the surrounding vegetation type. In other words, the vegetation within the college woods doesn't vary significantly enough to produce variation in the dicot:monocot ratios. Despite the variation in the quantities of produced materials by the common taxa within the College Woods, my results point to that lacking significance in producing a variation in the phytolith signature. This could be due to the primary phytolith contributors being present at all

plots regardless of vegetation type. As mentioned in the modern vegetation section, it is likely that beech (*Fagus grandifolia*), which was present in 95% of plots, contributed a majority of the dicot phytoliths morphotypes (**Table 1**). The ubiquity of beech (*F. grandifolia*) could be one such example of the composition of vegetation not varying enough to contribute to phytolith variation in the soil. Despite Kribel (2003) finding oaks (*Quercus spp*.) in 95% of all plots, during my collections, I found oaks to be present in only 7 out of the 15 plots used in this study based on where I collected my soil. Due to the higher variation in the production within the genus and the ~50% ubiquity, it is unlikely the variation of oak species between the plots within the woods meaningfully contributes to variations in the phytoliths present within each plot. This trend is likely to continue as beeches become more important in the canopy of the College Woods (Ware, 1970).

The average dicot:monocot ratio between all 15 plots is 0.25, a lower value than expected for a forest (Alexandre et al., 1997; Delhon et al., 2003). Due to a lack of studies conducted in the area, it is unknown if this ratio is a product of a unique circumstance within the College woods or if the value detected is typical of mixed hardwood forests of the Virginia Coastal Plain. At the time of this study, no other botanical or ecological phytolith studies have been conducted in the Virginia Coastal Plain. Phytoliths have been used in the region for archaeobotanical research focused primarily around colonial Virginia settlements but no work has been done to analyze the natural phytolith assemblages within the region (Sullivan, 1999; Sullivan and Kealhofer, 2004). As a result, it is unknown whether or not the College Woods is unique in this lower ratio. The lack of abundant phytolith producing dicots within the College Woods and extended coastal plain could explain the lower ratios found in this study. Additional analyses of the dicot:monocot ratios in different regions of the Coastal Plain are needed to be more confident with this

conclusion. It is also possible that within the College Woods, Poaceae and Cyperaceae are much more common than initially expected. Kribel (2003) found Carex in 95% of all plots indicating a major contributor of monocot morphotypes was present within nearly every plot. Poaceae was not seen as frequently in Kribel (2003) or my observations despite its dominance in the phytolith record. There are two possible explanations for this phenomenon:

1) Poaceae is much more common within the College Woods than observed, but due to deer overgrazing, the grasses do not last long into the summer. As noted in Kribel (2011), deer browsing within the College Woods increased drastically through the ’90s leading to the destruction of nearly all of the understory within the woods. Grasses may be visible in the early months of spring and summer, but by the time I made my collections in late July and August, the deer had consumed all the grasses on the forest floor. This could explain how grasses still dominated the phytolith count despite not being observed as abundant within the plots. The consumption of leaf material by deer can contribute to the phytolith load in the soil from their fecal deposits (Piperno, 2006; Kirillova et al., 2016; Strömberg et al., 2018).

2) The soil within the College Woods may be aged and weathered, in which there is the continual accumulation of phytoliths within the soil. Many of the plots established by Kribel (2003) are located in the relatively level uplands, where the slope is low enough that there is minimal erosion over at least the last 50 years (Steward Ware, personal communication, June 22, 2020). Due to higher phytolith contribution from Poaceae, over many years, the occasional grasses growing could accumulate enough phytoliths to lead to what I observed. The same would occur for dicots phytolith morphotypes as well with continual accumulation over time and due to the lower counts of the morphotypes. This could also explain the homogeneity of phytoliths between plots, with the modern vegetation not entirely reflective of the phytolith producing taxa

present in the area over the span of the soil age, but it is hard to determine whether or not this is the case without more soil work.

The lower than expected dicot:monocot values could also be indicative of preferential dissolution of dicot morphotypes (Cabanes et al., 2011). The common dicot morphotypes observed in this study – sheets, jigsaw, and polyhedrons – all possess fairly high surface area or are thin. These characteristics make it possible that the dicot morphotypes are experiencing higher degrees of dissolution within the College Woods sediments. While this is possibly an explanation for the lower dicot:monocot ratio, it is unlikely as my statistical tests showed that pH was not influencing the dicot:monocot ratio. If this was the case, I would expect to see plots with a high pH value associated with lower dicot:monocot ratios, but that is not what we see within the data I collected.

Despite the results of the statistical analyses suggesting homogeneity in terms of phytolith assemblages between plots as discussed above, I still detected some key differences between plots which may point to different environmental factors influencing the assemblages. These variations are likely a result of specific conditions at each plot. Despite some plots sharing elevations, some were located near a hillslope and others in channels (**Figure 9**). For example, plot 14 had the highest total phytolith per gram value and the highest dicot:monocot ratio out of all of the modern plots (**Appendix G**). This plot is also located in a topographic low point, residing on the edge of a channel. Phytoliths moving down the slope due to creep and runoff may be accumulating within the plot. Other potential factors influencing the phytolith assemblages are dissolution and exposures of the Yorktown formation. The Yorktown formation lies between 18 and 6 meters above sea level within the college woods (Rick Berquist, personal communication, March 11, 2021). Six of the fifteen plots used in this study fall within this range

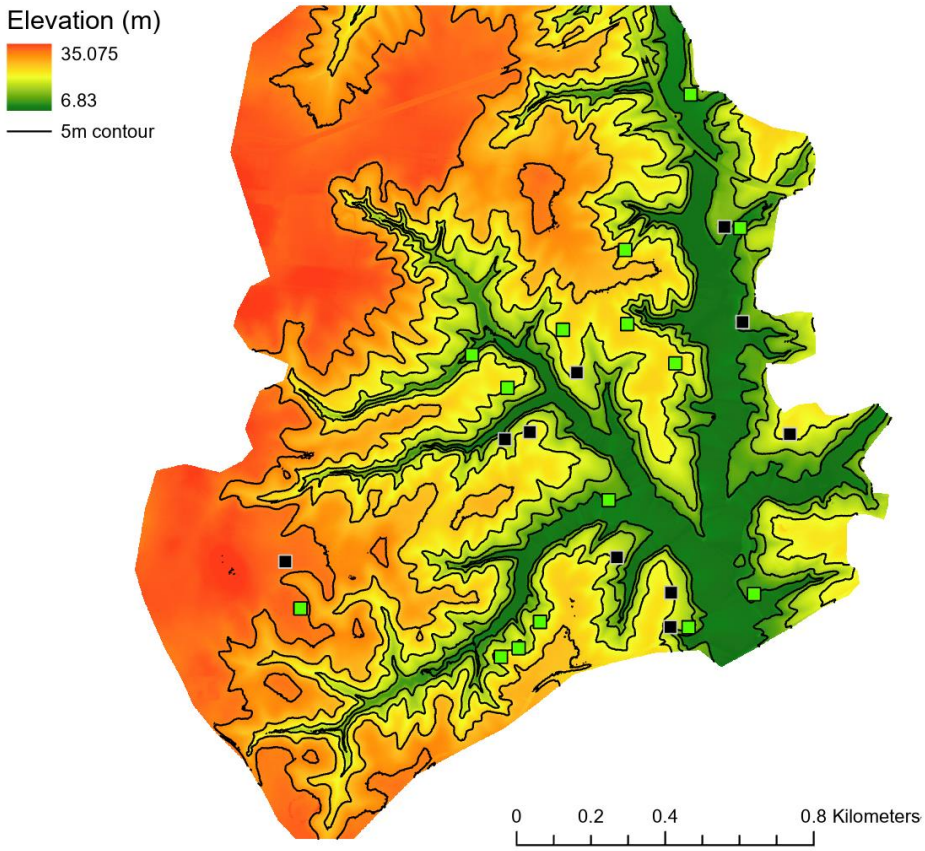

Figure 9: Three-meter resolution LIDAR DTM with 5m contour overlay of the College Woods. Plots analyzed in this study are colored green.

– plots C1.2, C5, P8, P12, P14, P18 (**Figure 4**). Although the measured pH values were all lower than alkaline values (pH >8), which is known to be the level at which phytoliths are dissolved, I did observe signs of dissolution on some of the phytoliths within the assemblages (Cabanes et al., 2011; **Appendix N**). I observed dissolution pits on a wide range of morphotypes as well as in plots not found within the Yorktown formation range. Additionally, the Yorktown formation is not universally exposed throughout the college woods, so some plots within the elevation, may not be exposed to the formation at the surface. During carbonate removal, none of the sampled plots reacted with the HCl, indicating the soils lacked any carbonates from the formation (**Appendix F**). Based on this, I believe that the presence of the Yorktown formation does not facilitate the dissolution of phytoliths within the College Woods. Instead, the observed partial

dissolution is likely caused by the reabsorption of dissolved silica by plants (Farmer et al., 2005). There may still be some influence on the phytolith assemblage by variations in the soil pH and exposures to the Yorktown formation, but none were detected in this study.

Overall, the modern phytolith assemblage of the College Woods is dominated by primarily monocot morphotypes with some signs of dissolution partially damaging the phytoliths. The assemblages I sampled from throughout the woods, did not vary enough to indicate a heterogeneous distribution within the College Woods. I can conclude that the phytolith assemblages within the woods, regardless of surrounding vegetation, elevation, pH, slope, or creek watershed, do not significantly differ from one another. This means the average modern phytolith assemblage can accurately portray the assemblages within the College Woods and serve as a modern analog to be compared to the phytolith assemblages within the Lake Matoaka sediment core.

Lake Sediment

I analyzed the phytolith assemblages within the sediment core from Lake Matoaka based on their similarity to the modern phytolith assemblage and whether or not they are explained by the variation in the modern phytolith data. The only two lake samples that exhibited values beyond two standard deviations from the average modern assemblage were the pre-lake sample's dicot:monocot ratio and the early lake (1700-1810) total phytoliths per gram value. This on its own indicates that the early lake and pre-lake environments differed from the modern College Woods. The inclusion of the PCA results adds weight to this conclusion, showing the pre-lake (20) is a significant outlier in terms of vegetative community and creek watershed and the early lake (19) is an outlier in terms of vegetative community as well as just falling outside of the

extremes of Pogonia creek. Because of these results, I can conclude that both the early lake and the pre-lake are distinct from the modern phytolith assemblage.

The pre-lake sample spanned the last 24cm of the core, from 126.0cm to 150.0cm. The sediment was very high in organic matter, taking the longest out of all the samples to finish reacting during the organic removal step of extraction (**Appendix I**). Balascio et al. (2019) describe the material as sandy organic-rich peat. Based on my observations during the extraction process, the pre-lake sample contained the most sand compared to the other four lake samples. It is theorized that this high volume of sand in the pre-lake portion of the core is due to coring into the pre-lake college creek – Archer's Hope creek – which likely had higher energy and thus contributed more sand (Nick Balascio, personal communication, April 2021). This may have influenced the phytolith assemblage of the sample as well since past studies have shown riparian depositional environments to be less reliable than lacustrine in terms of phytolith assemblages. Often these depositional environments' higher energy results in the deposition and transport of phytoliths within the sediment (Madella and Lancelotti, 2012; Strömberg et al., 2018). However, without more cores from the same aged material, it is impossible to determine whether or not the assemblage was influenced by the different depositional environment. During extraction, I also made observations of green in color sediments within the pre-lake core (**Appendix J**). While I did not officially classify the mineral, it is likely glauconite. Glauconite, which is typically an indicator of marine sediments, is present within the Cobham Bay member of the Eastover formation (Ward and Blackwelder, 1980). The Cobham Bay member underlies the Yorktown Formation and is present below ~6 meters above sea level in the College Woods (Rick Berquist, personal communication, March 15, 2021). To my knowledge, the only easily accessible exposure of the member is below the Lake Matoaka spillway on the opposite side of Jamestown

road to the lake. This likely indicates that the glauconitic sand at the bottom of the core is due to the pre-lake college creek cutting into the Cobham Bay member of the Eastover formation. Since the Yorktown formation could not be shown to be influencing the phytolith assemblages of the modern College Woods, it is unlikely the Eastover formation influenced the phytolith assemblage of the pre-lake. The combination of the high organic matter and the glauconitic sand indicate that the pre-lake college creek was likely a wetland with a higher energy stream flowing through it.

The sediment from the pre-lake portion of the core, because of the different depositional environment, does not reflect the vegetational communities of the upland portions of the modern College Woods. The dry-mesic upland soils likely hosted a mature hardwood forest, but if the core was indeed taken from the center of the Archer's Hope creek, then the phytoliths from the uplands may have been transported farther downstream. The phytoliths within the pre-lake sample likely came from deposition in place within the peat material. This implies that the phytoliths represent only the immediate wetland surrounding the creek, rather than the entire watershed as with the lake samples. This is an important result in terms of the applicability of phytoliths to study the pre-lake College Woods. Based on the current core, the phytolith assemblage of the pre-lake is unable to reflect the entire College Woods. The use of a different vegetative proxy like pollen may be more prone to representing the upland vegetation, but it would also be influenced by pollen coming from outside of the watershed. I believe that to overcome this issue, coring into a depositional feature of the creek, like a point bar, would enable a more thorough analysis of the vegetation growing in the upland regions. I do believe that the pre-lake phytolith assemblage can still be interpreted in terms of the vegetative community of the

wetland it represents and how that can be compared to the modern wetlands of the College Woods.

The pre-lake phytolith assemblage has a dicot:monocot ratio of 0.43 (**Figure 7**). This value is greater than two standard deviations from the average modern dicot:monocot ratio of 0.25 (**Table 6**). In the PCA analysis, the pre-lake sample plotted high on PCA2 and in the positives of PCA1, indicating it is influenced by high dicot:monocot ratio values and high multicell:singlecell ratio values. It is important to note that the multicell:singlecell ratio of the pre-lake same is lower than 9 of the modern plots as well as the average modern value (**Appendix E** and **H**). All of the lake samples have lower multicell:singlecell values, likely due to disarticulation during the transport and deposition. Despite this, none of the multicell:singlecell ratio values are significantly different from the modern phytolith assemblages, limiting the degree to which I can interpret the deposition conditions of the lake phytoliths (**Table 6**). The Higher ratio values would indicate a lot more deposition in place, which makes sense for the modern plot soil samples, but is not true for the lake sediments. The higher value of the dicot:monocot ratio indicates the vegetation of the surrounding area before Lake Matoaka was much more influenced by forested vegetation.

An important distinction to make is that the dicot:monocot ratio indicates more generally between forest and grassland rather than specific dicots and monocots because I only identified to the level of monocot and dicot. Major gymnosperm trees like pines (*Pinus spp.*) and cedars (*Juniperus spp.*), which produce phytoliths, are grouped into the dicot classification because the morphotypes they produce are shared by some dicots (**Table 4**). This means that despite the higher dicot:monocot ratio, it does not necessarily indicate a higher presence of dicots, rather just more likely that area had a larger influence from trees. I believe the likely explanation for the

ratio is the presence of Bald Cypresses (*Taxodium distichum*). Cypresses belong to the family Cupressaceae, which is a Tier 2 family according to Piperno (2006). Based on my modern vegetation work with *Juniperus virginiana* in the same family, the cypress likely produces phytoliths from its leaves at an expected level (**Table 4**). These cypress phytoliths would fall into the dicot side of the dicot:monocot ratio, increasing the value. The vegetation in the pre lake was likely a cypress swamp, with higher numbers of tree species contributing phytoliths into the sediment and less common grasses and sedges growing in the shallower water. This is unable to be confirmed until the phytolith morphotypes are recorded to get a better understanding of what specific plants are present in the environment. Historic records have indicated that the area was classified by early European colonists as a swamp, one of the first surveys of the area that would become Williamsburg called the area Archer's Hope Swamp, named after Archer's Hope Creek (**Appendix K**). To my knowledge, there are no descriptions of the swamp, but it is possible conclusions can be drawn based on modern counterparts.

The Great Dismal Swamp (GDS) is located ~50 miles southeast of the College Woods. GDS presently covers ~850km^2 of land on the border between North Carolina and Virginia, but historically the swamp reached a size of over 2,000km^2 (Mitsch and Hernandez, 2013). Much of the historic range of the swamp was lost due to logging and irrigation, but there exist several first-hand accounts of the vegetation within the swamp during the early 18th century. William Byrd II described the swamp when surveying the Virginia-North Carolina border. In his account, Byrd described seeing thickets of white cedar (*Thuja occidentalis*) and Bald Cypress (*Taxodium distichum*) throughout the swamp (Byrd, 1958; Levy, 1991). Both communities are present within the swamp today, but in greatly reduced numbers (Dabel and Day, 1977). The vegetation within Archer's Hope Swamp was likely similar to the GDS as the two areas are geographically

and geologically similar. If this is the case, that would imply that cypresses have been completely removed from the vegetation of the College Woods. The tributaries entering Lake Matoaka all have relatively low slopes with shallow wetlands forming at each mouth. Despite these wetlands, no cypresses are present within the College Woods (Kribel, 2003). We are left with two questions: 1) if there were never cypresses present in the area, then what type of swamp was Archer's Hope Swamp? 2) If there were cypresses then where did they go? I believe the latter question is more accurate, as Bald Cypresses are present near bodies of water all over the Coastal Plain (McMillan, 1974). Despite viable cypress habitat around the lake, the species has not returned to the area, suggesting that some anthropogenic activity has erased them from the ecosystem or facilitated conditions no longer tolerable to the species. Based on my results from the sediment directly above the pre-lake and accounts of cypress wood being used in the construction of Williamsburg, I believe this activity may be logging (The William and Mary Quarterly).

The early lake sediments spanned from 126.0cm to 94.5cm correlating to the years 1703 – 1807 based on the age-depth model developed in Balascio et al. (2019). The 31.5cm of sediment represents ~104 years indicating a slower sedimentation rate into the late during this time when compared to the more modern samples. For example, the most modern sample – spanning from 0.0cm to 31.5cm – represents a span of ~60 years despite the same range within the core. This is important because the early lake sample stands out in terms of its total phytolith per gram value. The total phytoliths per gram of the early lake sample is ~7.5σ from the mean modern total phytoliths per gram indicating the count is distinct from the modern assemblage (**Table 6**). The PCA places the early lake sample (19) high on PCA1 and in the low negatives of PCA2 (**Figure 8**). This indicates the influence of the total phytoliths per gram on the variance. The PCA

grouped by vegetation places the sample as distinct from all the modern vegetative communities, but it falls just beyond the Pogonia creek watershed type. This means that the early lake is distinct only in terms of phytoliths per gram and falls very close to the natural variation contained within Pogonia creek. Based on these three results, I am confident that the early lake phytolith assemblage is distinct from the modern phytolith assemblage in terms of phytoliths per gram.

The high total phytolith per gram value is indicative of a major change within the watershed of Lake Matoaka. The highest phytoliths per gram value of the modern assemblage is plot 14 (**Appendix E** and **G**). This is the sample I hypothesized as having a high count due to its location within the channel. Plot 14 had a dicot:monocot ratio of 0.40 while the early lake sample has a ratio of 0.24. This difference in ratios but similar phytoliths per gram indicates a higher influence of monocots in the early lake sediment. This is an indication of the watershed being cleared at the time of the lake's creation. The clearing of the primarily dicotyledon trees and the subsequent succession of grasses and other monocots into the area. The increased production of phytoliths by grasses after a clearing event would drive up the total phytoliths per gram and drive down the dicot:monocot ratio. My results are not that simple, as the dicot:monocot ratio of the early lake is not significantly different from the average of the modern phytolith assemblage. This points to several possible explanations:

1) The first possible explanation for the high phytolith count and close to average dicot:monocot ratio is related to the succession that would occur following a clearing event. It is possible that with the rise of grasses in the watershed, there was also an influx of dicotyledon shrubbery. The primary shrub of the modern College Woods is *Vaccinium spp*. which is low in phytolith production (Piperno, 2006). With the associated decrease in canopy cover, phytolith-

producing herbs and shrubs may have undergone a population boom, triggering a higher influx of dicot phytoliths into the lake. Spencer et al. (2001) analyzed the succession of southeastern Virginia hardwood wetlands after clear-cutting events. They found that in most cases where cypresses are present, they are the dominant community during the regrowth. If the cypresses do not recover from the clearing, then the herbaceous material dominates the community. One of the hypotheses presented by the authors is that a lack of drawdown prevents cypresses, specifically *T. distichum*, from germinating. Drawdown in this context refers to the lowering of water levels within a wetland. It is contrary to a reflood, which raises the water level back to initial levels. *T. distichum* requires drawdown to germinate, with seeds often failing to germinate in flooded soils (Middleton, 2009). The compounding factors of damming College creek triggering the flooding of Lake Matoaka and the clearing of mature trees together can explain the lack of *T. distichum* in the College Woods today and may suggest a mechanism for dominance of herbaceous vegetation after the clearing. As for the more mesic uplands, clearing likely led to similar vegetation, with higher abundances of grasses. These upland areas also hosted the majority of land use by the European colonists as I will discuss in the later lake samples.

2) The higher than expected dicot:monocot ratio may also be indicative of an increase in available silica for uptake. As discussed in the modern vegetation section, dicot plants like oaks (*Quercus*) and beeches (*F. grandifolia*) create phytoliths through passive uptake of available silica. Grasses generate phytoliths through the active uptake of dissolved silica. This difference could point to a possible successional process in terms of the development of a phytolith assemblage. An environment starts with a relatively poor level of dissolved silica available for uptake into plants, due to a low or neutral pH value. The majority of silica is not in silicic acid gel form within the sediments, unavailable for uptake by the majority of plants. An influx of

active silica uptaking taxa, such as grasses, into the area could increase the amount of available silica by generating phytoliths from the silica within the sediments. The higher concentrations of available silica in the form of phytoliths in the sediment can then facilitate the generation of phytoliths within the passive uptake taxa. The result would take a landscape that has a low phytolith abundance and low dissolved silica content and produce a landscape rich in phytoliths from both grasses and dicots. This scenario is potentially what I observed within the early lake phytolith assemblage. The initial clearing of the trees enables grasses to dominate the landscape, producing large quantities of phytoliths with the soil. As shrubs and herbaceous dicots began to grow, the high quantity of phytoliths enabled the uptake of silica and the production of dicot morphotypes. This process is merely a hypothesis at the moment but examining the core in shorter time intervals could provide some insight as to whether or not this process appears to be active.

3) The third possible explanation for the high dicot:monocot ratio is that the clearing of the vegetation within the watershed increased erosion into the lake which in turn increased the influx of phytoliths into the lake. I believe this scenario is unlikely because the sedimentation rate of the modern lake is much higher than in the early lake (Balascio et al., 2019). As mentioned earlier, the same span of 30.5cm in the early lake represents over 100 years while in the modern lake it represents closer to 60. The lower sedimentation rate in the earlier lake suggests that the high influx of phytoliths is a product of the vegetation and not an artifact of a different depositional environment than the modern lake.

The third lake sample (18), spanning from approximately 1810 to 1890, is the only sample to fall within 68% of the variation of the modern vegetation groups in the PCA. The two most modern samples (16 and 17) however, do not fall within any of the modern vegetation groups

despite the groups existing at the time of deposition (**Figure 8**). While these results are not what I expected, the two most modern lake samples still fall within the natural variation of the vegetation of the modern woods. It is likely that the lake is overrepresenting the phytoliths of the area, but not to a degree where they no longer reflect the modern assemblage (Strömberg et al., 2018). Based on the PCA, lake sample 3 falls within the variation of the mixed vegetation type. This indicates that some portions of the watershed had begun to reforest since the initial creation of the lake. This is supported by the fact that a map created in 1862 shows some areas surrounding the lake to be forested at the time, indicating that the trees were present (**Appendix M**). Based on my phytolith results, I am confident in asserting that these tree communities reflected the modern mixed tree communities we see in the woods today.

In addition to all of the phytoliths, I observed fragmented and complete diatoms within all five of the lake samples. The common observations of diatoms within the sediment indicate how productive the lake was during different years. The fact that most of the diatoms were fragmented within the sediment fits with the low multicell:singlecell ratio observed in the lake phytolith assemblages. The multicell morphotypes were likely disarticulated during transport and deposition, much like the diatoms within the sediment due to slow rates of burial. Based on my qualitative observations, diatoms were relatively low in the pre-lake and sample 2 (~1960-1890) and most commonly observed in the early lake sample and modern lake sample. These results confirm the trends in biogenic silica observed by Balascio et al. (2019) in the lake core. This suggests the lake was highly productive early on before becoming less productive in the late 19th and early 20th centuries. This indicates the possibility of poor land-use practices within the lake watershed, causing an excess of nutrients to wash into the lake.

During the later 17th century, much of the land that we call the College Woods today was owned by Thomas Ballard (Monroe and Lewes, 2016). Ballard would go on to sell some of his property to James Blair for the construction of William & Mary and some in the northeastern portion of the College Woods to the Bright family. Records indicate that this property owned by the Brights, named New Hope, was a farm that made use of enslaved labor. The property grew corn, wheat, and oats and held livestock like cows and sheep (Monroe and Lewes, 2016). The presence of the New Hope farm in the area as well as possible other farms on the western side likely contributed to increased runoff and led to higher productivity in the lake. The subsequent decrease in the levels may reflect the gradual decrease of productivity in the New Hope farm and the gradual acquisition of the farm by William & Mary in 1928 (Monroe and Lewes, 2016). The decrease may also be indicative of the destruction of the lake's dam during the Civil War (Balascio et al., 2019). The 1862 map created not only shows the location of some reforested areas within the watershed but also shows a semi-drained Lake Matoaka **(Appendix M**). Future research on diatom abundances in the 20th century would potentially indicate a rising population within Williamsburg and the expansion of developed landcover north of the lake (Balascio et al., 2019).

Within the sediments of the lake, I also observed charcoal in different abundances throughout the core (**Appendix P**). I made qualitative observations of the overall abundance of charcoal within each sample as well as the majority type of charcoal. The pre-lake sample (20) was lower than the other four lake samples in observed charcoal indicating a lower presence of anthropogenic activity in the immediate area. Samples three (18) and four (19), the oldest lake samples, had a relatively low observation of charcoal in the sediment. Between 1700 and 1900, Williamsburg went through several major events and population increases, which I expected to

produce high frequencies of charcoal but this is not the case (Balascio et al., 2019). Between 1900 and 2015 (samples 16 and 17) I observed a much higher abundance of charcoal in the sediment compared to the previous 3 lake samples. This is indicative of the rapid urbanization and population growth the city went through during the 20th century. I observed two primary types of charcoal, burnt wood remnants, and fly ash. In the modern lake sediment, not only was there the highest amount of charcoal present but there was also a high ratio of fly ash in the sediment. Fly ash indicates that the charcoal is not necessarily coming from a landscape fire, but could be from combustion engines, chimneys, and other aerosols. A thorough charcoal study could help determine specific fire events within the College Woods as well as support evidence of urban expansion in the region throughout the last three centuries.

Conclusions

Future work

My work can be taken in many future directions, all of which would provide meaningful insight into the phytolith assemblages of the College Woods and the vegetative history of the area. A key step would be to create a list of morphotypes for each of the identified common taxa within the woods. This reference collection would not only be valuable for future phytolith studies in the College Woods and the Virginia Coastal Plain but would also provide insight into the production of phytoliths by taxa that have not gotten a lot of attention in the literature (**Appendix Q**). With this information, it would be valuable to return to the modern phytolith assemblages and identify the abundances of the different morphotypes within the soil. This information would enable the identification of the specific phytolith contributing taxa at each plot. The addition of the 10 plots I did not analyze within this study would increase the confidence of the results of the statistical analyses and provide insight into the variation between

plots. Additional confidence in my results could be gained by examining the modern phytolith assemblages of other mixed-hardwood forests within the Coastal Plain of Virginia. This would determine if the woods are an outlier or if the values I identified are typical of forests in this region, supporting my conclusions based on the environmental factors studied.

Mapping the Yorktown formation within the College Woods would not only provide insight into the patterns of preservation for phytoliths through the woods but would also be a valuable resource for identifying areas of interest when it comes to rare and endangered species within the College Woods. The additional use of sediment cores taken from the upland regions of the College Woods would enable the study of the changes in vegetation in areas that may not have been reflected as well in the lake sediment. It would have the additional benefit of identifying areas that were used in agriculture due to the soil being turned frequently. I believe the use of pollen within the lake core would provide an additional level of confidence to my findings. Pollen could indicate not only the pre-lake wetland vegetation but the taxa present in the uplands and region as well. Finally, the use of more samples from throughout the core would enable higher resolution data on the vegetative trends within the watershed. Sampling within the silty strata of the lake sediment may provide differing phytolith counts due to a high rate of preservation via bonding to oxides. This data would provide insight into the more specific events in the College Woods, enabling a better understanding of the vegetative history.

Conclusion

The use of phytoliths to quantify the modern vegetation of the College Woods was successful. Based on the common phytolith producing taxa within the woods, I was able to determine Beeches (*F. grandifolia*) as the primary phytolith producing dicots within the woods, despite oaks (*Quercus spp.*) having the higher biomass. The results of my modern phytolith

assemblage analysis point to a lower dicot:monocot ratio than expected based on standing vegetation communities indicating an overrepresentation of monocots in phytolith assemblages within the College Woods. I also found that despite highly calcareous regions throughout the woods due to exposure of the Yorktown formation, there was no indicated impact on the phytolith assemblages. In the same realm, the overall phytolith-producing taxa within the College Woods are homogenous, enabling interpretations of the phytoliths of the woods as a whole.

Overall, it is difficult to determine when the vegetation within the College Woods was cleared. Equally as challenging is identifying the point when the College Woods as we know it today began to take form. I believe that this is not a flaw in the applicability of phytoliths, but instead in the chosen method of study. By sampling over broad time spans within the lake, the abrupt transitions of clearing events are lost. It is also possible that the dicot:monocot ratio falls short of being able to function as a proportion of forest cover proxy. At no point throughout the lake's history was the dicot:monocot ratio outside of the variation that exists within the modern College Woods, despite maps indicating the vegetation within the watershed to be different in the proportions of cleared to forested land. I also believe that up until the 20th century the landcover within the College Woods was heterogeneous, with some areas cleared and others forested. While the modern College Woods are homogenous in terms of phytolith assemblages, this is likely not true at different periods throughout the lake's history, making it difficult to interpret the changes in phytoliths holistically.

The phytolith assemblage of the early lake is distinct from the modern phytoliths. The abundance of phytoliths in the sample indicates a higher abundance of monocots in the watershed and evidence of grasses covering the landscape. The differences between the pre-lake

phytolith assemblage and the modern phytolith assemble are distinct. In that respect, the vegetation that was present within the wetland of Archer's Hope swamp was distinct from the modern College Woods. The wetlands within the College Woods did not produce phytolith signatures outside of the variation within the woods as a whole. This indicates that the community within the swamp was unique from the modern wetlands and has not returned to the area. Despite the protected status the woods receive by William & Mary, the legacy of the damming of Archer's Hope Creek and the impact of the historic landscape activity in the area remain over 300 years later. Lake Matoaka is an inseparable part of the William & Mary campus. The surrounding College Woods are host to countless studies, including this one, and yet their protected status hides the fact that the creation of Lake Matoaka has caused permanent changes to the vegetation and communities present within the watershed.

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Appendix

Appendix A

Table of tier I and II taxa as designated by Piperno (2006) and their associated abundancies within the College Woods as reported by Kribel (2003).

Tier	Family	Genus	Species	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16	Plot 17	Plot 18	Plot 19	Plot 20	Total	Ubiquity
1	Cyperaceae	*Carex*	*spp*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
2	Fagaceae	*Fagus*	*grandifolia*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
2	Cupressaceae	*Juniperus*	*virginiana*	P	P	P	P	P		P	P	P	P	P	P	P	P	P	P	P		P	P	18	90
1	Magnoliaceae	*Liriodendron*	*tulipifera*	P	P	P		P	P	P	P	P	P	P	P	P	P	P	P	P		P		17	85
1	Magnoliaceae	*Magnolia*	*grandifolia*	P	P	P	P	P	P	P		P	P	P	P	P	P	P	P	P				16	80
2	Pinaceae	*Pinus*	*virginiana*	P					P	P	P	P	P	P	P	P	P	P		P	P		P	14	70
2	Dryopteridaceae	*Polystichum*	*acrostichoides*	P	P	P	P		P	P	P	P	P			P	P	P	P	P				14	70
2	Fagaceae	*Quercus*	*alba*	P	P	P	P	P			P	P		P	P		P		P	P		P	P	14	70
2	Fagaceae	*Quercus*	*velutina*			P	P	P	P	P		P	P	P			P	P		P		P	P	13	65
2	Fagaceae	*Quercus*	*rubra*	P	P		P	P	P		P			P	P	P			P	P				11	55
2	Fagaceae	*Quercus*	*falcata*	P												P	P	P	P			P		6	30
2	Fagaceae	*Quercus*	*nigra*		P									P	P		P	P						5	25
2	Fagaceae	*Quercus*	*phellos*					P	P		P											P		4	20
2	Fagaceae	*Quercus*	*coccinea*									P			P							P	P	4	20
2	Fagaceae	*Quercus*	*michauxii*							P					P	P	P							4	20
1	Poaceae	*Dichanthelium*	*spp*											P			P			P				3	15
1	Moraceae	*Morus*	*rubra*			P						P								P				3	15
1	Orchidaceae	*Cypripedium*	*acaule*						P												P			2	10
2	Pinaceae	*Pinus*	*taeda*														P						P	2	10
2	Fagaceae	*Quercus*	*muehlenbergii*												P					P				2	10
1	Ulmaceae	*Ulmus*	*rubra*																	P	P			2	10
1	Asteraceae	*Aster*	*simplex*																		P			1	5
2	Fagaceae	*Castanea*	*dentata*	P																				1	5
2	Fagaceae	*Castanea*	*pumila*																				P	1	5
1	Asteraceae	*Elephantopus*	*sp*																	P				1	5
1	Orchidaceae	*Goodyera*	*pubescens*			P																		1	5
1	Orchidaceae	*Malaxis*	*unifolia*									P												1	5
1	Poaceae	*Microstegium*	*vimineum*																		P			1	5
1	Asteraceae	*Mikania*	*scandens*																		P			1	5
1	Orchidaceae	*Orchis*	*spectabilis*																	P				1	5
1	Urticaceae	*Pilea*	*fontana*																		P			1	5
1	Poaceae	*Poaceae*	*sp 1*																		P			1	5
1	Poaceae	*Poaceae*	*sp 2*																		P			1	5
1	Asteraceae	*Prenanthes*	*sp*							P														1	5
1	Asteraceae	*Senecio*	*sp*																		P			1	5
1	Asteraceae	*Taraxacum*	*officinale*																	P				1	5
1	Ulmaceae	*Ulmus*	*alata*																		P			1	5
1	Annonaceae	*Asimina*	*triloba*																					0	0
1	Asteraceae	*Hieracium*	*sp*																					0	0

Appendix B

Table of all common taxa within College Woods regardless of phytolith production level as reported by Kribel (2003).

Tier	Family	Genus	Species	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16	Plot 17	Plot 18	Plot 19	Plot 20	Total	Ubiquity
5	Sapindaceae	*Acer*	*rubrum*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	20	100
1	Cyperaceae	*Carex*	*spp*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
n/a	Cornaceae	*Cornus*	*florida*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
2	Fagaceae	*Fagus*	*grandifolia*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
n/a	Aquifoliaceae	*Ilex*	*opaca*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
5	Rosaceae	*Prunus*	*serotina*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	19	95
5	Juglandaceae	*Carya*	*pallida*	P	P	P	P		P	P	P	P	P	P	P	P	P	P	P	P		P	P	18	90
n/a	Celastraceae	*Euonymus*	*americana*	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P			18	90
2	Cupressaceae	*Juniperus*	*virginiana*	P	P	P	P	P		P	P	P	P	P	P	P	P	P	P	P		P	P	18	90
1	Magnoliaceae	*Liriodendron*	*tulipifera*	P	P	P		P	P	P	P	P	P	P	P	P	P	P	P	P		P		17	85
n/a	Ebenaceae	*Diospyros*	*virginiana*	P		P		P	P	P	P	P	P	P	P	P	P	P	P			P	P	16	80
1	Magnoliaceae	*Magnolia*	*grandifolia*	P	P	P	P	P	P	P		P	P	P	P	P	P	P	P	P				16	80
5	Vitaceae	*Parthenocissus*	*quinquefolia*	P	P	P	P		P	P	P		P	P	P	P	P	P	P	P	P			16	80
5	Ericaceae	*Vaccinium*	*pallidum*				P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	16	80
5	Ericaceae	*Vaccinium*	*stamineum*				P	P	P	P	P	P	P	P	P	P	P	P	P	P		P	P	16	80
5	Rubiaceae	*Mitchella*	*repens*	P	P	P	P	P	P	P	P	P		P	P	P	P	P	P					15	75
2	Pinaceae	*Pinus*	*virginiana*	P					P	P	P	P	P	P	P	P	P	P	P	P	P		P	14	70
2	Dryopteridaceae	*Polystichum*	*acrostichoides*	P	P	P	P		P	P	P	P	P			P	P	P	P	P				14	70
2	Fagaceae	*Quercus*	*alba*	P	P	P	P	P			P	P		P	P		P		P	P		P	P	14	70
5	Juglandaceae	*Carya*	*tomentosa*	P	P	P	P			P	P	P			P	P	P	P	P				P	13	65
n/a	Nyssaceae	*Nyssa*	*sylvatica*		P	P	P	P				P		P	P	P		P	P	P		P	P	13	65
2	Fagaceae	*Quercus*	*velutina*			P	P	P	P	P		P	P	P			P	P		P		P	P	13	65
5	Juglandaceae	*Carya*	*glabra*	P	P	P	P				P		P	P	P	P	P	P	P					12	60
5	Vitaceae	*Vitis*	*rotundifolia*			P	P			P	P	P		P	P	P	P	P		P		P		12	60
5	Vitaceae	*Vitis*	*sp*		P	P		P	P	P	P			P	P		P	P	P		P			12	60
5	Rosaceae	*Amelanchier*	*arborea*	P					P		P				P	P		P	P	P	P	P	P	11	55
5	Juglandaceae	*Carya*	*cordiformis*	P	P	P	P				P	P			P	P	P		P	P				11	55
2	Fagaceae	*Quercus*	*rubra*	P	P		P	P	P		P			P	P	P			P	P				11	55
5	Ericaceae	*Chimaphila*	*maculata*					P	P	P			P	P		P	P		P			P	P	10	50
n/a	Altingiaceae	*Liquidambar*	*stryraciflua*	P	P		P	P	P			P						P	P	P		P		10	50
5	Ericaceae	*Oxydendrum*	*arboreum*	P	P		P	P	P	P	P			P					P	P				10	50
5	Smilacaceae	*Smilax*	*spp*	P			P		P	P			P	P		P	P			P	P			10	50
n/a	Anacardiaceae	*Toxicodendron*	*radicans*		P	P				P		P	P	P		P		P		P	P			10	50
5	Asparagaceae	*Polygonatum*	*biflorum*	P			P	P	P	P	P	P					P	P						9	45
n/a	Lauraceae	*Sassafras*	*albidium*					P			P			P	P		P		P	P		P	P	9	45
5	Ericaceae	*Vaccinium*	*fuscatum*				P	P	P					P	P		P	P				P	P	9	45
n/a	Adoxaceae	*Viburnum*	*acerifolium*			P		P	P			P	P	P		P	P		P					9	45
5	Ericaceae	*Gaylussacia*	*baccate*					P	P			P	P	P								P	P	7	35
5	Ericaceae	*Gaylussacia*	*frondosa*	P	P		P	P	P													P	P	7	35
4	Fabaceae	*Desmodium*	*sp*	P				P		P					P	P				P				6	30
2	Fagaceae	*Quercus*	*falcata*	P												P	P	P	P			P		6	30
5	Ericaceae	*Vaccinium and Gaylussacia*	*spp*					P	P					P		P						P	P	6	30
2	Fagaceae	*Quercus*	*nigra*		P									P	P		P	P						5	25
4	Fabaceae	*Cercis*	*canadensis*									P				P	P			P				4	20
5	Dioscoreaceae	*Dioscorea*	*quarternata*		P			P	P				P											4	20
5	Rubiaceae	*Galium*	*sp*			P						P				P				P				4	20
2	Fagaceae	*Quercus*	*phellos*					P	P		P											P		4	20
2	Fagaceae	*Quercus*	*coccinea*									P			P							P	P	4	20
2	Fagaceae	*Quercus*	*michauxii*							P					P	P	P							4	20
5	Asparagaceae	*Smilacina*	*racemosa*		P					P							P		P					4	20
5	Ericaceae	*Vaccinium*	*spp*	P	P	P					P													4	20

Appendix C

List of the specimens used in the modern vegetation phytolith analysis. LMV013 – LMV016 came from material donated to the study by the William and Mary Herbarium (WILLI). I collected all other specimens during the summer of 2020.

ID	Family	Genus	Species	Material	Collection Date	Lat	Long
LMV001	Fagaceae	Quercus	velutina	leaf	7/10/2020	37.2704051	-76.6996172
LMV002	Fagaceae	Quercus	velutina	bark	7/10/2020	37.2704051	-76.6996172
LMV003	Fagaceae	Quercus	phellos	leaf	7/10/2020	37.272384	-76.7044897
LMV004	Fagaceae	Quercus	phellos	bark	7/10/2020	37.272384	-76.7044897
LMV005	Cupressaceae	Juniperus	virginiana	leaf	7/10/2020	37.2703883	-76.7040016
LMV006	Cupressaceae	Juniperus	virginiana	bark	7/10/2020	37.2703883	-76.7040016
LMV007	Fagaceae	Quercus	rubra	leaf	7/10/2020	37.2722773	-76.6930562
LMV008	Fagaceae	Quercus	rubra	bark	7/10/2020	37.2722773	-76.6930562
LMV009	Magnoliaceae	Magnolia	grandiflora	leaf	7/8/2020	37.278586	-76.706533
LMV010	Magnoliaceae	Magnolia	grandiflora	bark	7/8/2020	37.278586	-76.706533
LMV011	Fagaceae	Fagus	grandifolia	leaf	6/16/2020	38.419291	-77.529616
LMV012	Fagaceae	Fagus	grandifolia	bark	6/16/2020	38.419291	-77.529616
LMV013	Fagaceae	Quercus	michauxii	leaf	1992-1994	n/a	n/a
LMV014	Fagaceae	Quercus	michauxii	bark	1992-1994	n/a	n/a
LMV015	Pinaceae	Pinus	virginiana	leaf	1992-1994	n/a	n/a
LMV016	Pinaceae	Pinus	virginiana	bark	1992-1994	n/a	n/a
LMV017	Fagaceae	Quercus	nigra	leaf	7/21/2020	37.270888	-76.7096235
LMV018	Fagaceae	Quercus	nigra	bark	7/21/2020	37.270888	-76.7096235
LMV019	Fagaceae	Quercus	coccinea	leaf	7/21/2020	37.2714051	-76.6995863
LMV020	Fagaceae	Quercus	coccinea	bark	7/21/2020	37.2714051	-76.6995863
LMV021	Fagaceae	Quercus	alba	leaf	6/16/2020	38.419834	-77.530877
LMV022	Fagaceae	Quercus	alba	bark	6/16/2020	38.419834	-77.530877
LMV023	Magnoliaceae	Liriodendron	tulipfera	leaf	6/16/2020	38.419339	-77.530836
LMV024	Poaceae	Microstegium	vimineum	leaf	7/8/2020	37.278608	-76.706272
LMV025	Poaceae	Brachyelytrum	erectum	leaf	7/9/2020	n/a	n/a
LMV026	Poaceae	Andropogoneae	NULL	leaf	7/9/2020	n/a	n/a
LMV027	Poaceae	Dicanthelium	NULL	leaf	7/9/2020	n/a	n/a
LMV028	Poaceae	NULL	NULL	leaf	7/9/2020	n/a	n/a
LMV029	Annonaceae	Asimina	triloba	leaf	September, 2020	37.2708936	-76.7146667
LMV030	Annonaceae	Asimina	triloba	bark	September, 2020	37.2708936	-76.7146667

Verbatum habitat	NOTES
Large tree behind CW Magazine, next to road, Williamsburg, VA	
Large tree behind CW Magazine, next to road, Williamsburg, VA	
Large Tree across from pasture, near intersection with Nassau, Williamsburg, VA	
Large Tree across from pasture, near intersection with Nassau, Williamsburg, VA	
Med size tree, next to lot p4 in CW, Williamsburg, VA	
Med size tree, next to lot p4 in CW, Williamsburg, VA	
Small tree next to Capitol Building and Nicholson Street, Williamsburg, VA	
Small tree next to Capitol Building and Nicholson Street, Williamsburg, VA	
Large tree growing in the backyard of my house, Highland Park, Williamsburg, VA	
Large tree growing in the backyard of my house, Highland Park, Williamsburg, VA	
Small tree ~15 feet from house garage, Stafford, VA	
Small tree ~15 feet from house garage, Stafford, VA	
Charles City County, VA	Herbarium Specimen, Mark Stoetzer #964
Charles City County, VA	Herbarium Specimen, Mark Stoetzer #964
Charles City County, VA	Herbarium Specimen, Mark Stoetzer #240
Charles City County, VA	Herbarium Specimen, Mark Stoetzer #240
Large tree in front of the Wren building on the sunken garden side, Williamsburg, VA	
Large tree in front of the Wren building on the sunken garden side, Williamsburg, VA	
Large tree growing on the side of sidewalk next to DOG street and adjacent to Chowning's Cider Stand, Williamsburg, VA	
Large tree growing on the side of sidewalk next to DOG street and adjacent to Chowning's Cider Stand, Williamsburg, VA	
Uphill from across fire pit, surrounded by ferns (Polystichum acrostichoides). Stafford, VA	
Uphill from across fire pit, surrounded by ferns (Polystichum acrostichoides). Stafford, VA	
~5m downhill from old road, opposite a stand of pines, Stafford, VA	
Large partch adjacent to 606 N Henry St, Williamsburg, VA	
Within the College Woods	Specific Location was not recorded
Within the College Woods	Specific Location was not recorded
Within the College Woods	Specific Location was not recorded
Within the College Woods	Specific Location was not recorded
Small ~1m tall shrub growing adjent to crim dell trail behind the Wellness Center, Williamsburg, VA	
Small ~1m tall shrub growing adjent to crim dell trail behind the Wellness Center, Williamsburg, VA	

Appendix D

Table of the weights of the modern vegetation samples and the weight of material produced following the extraction protocol. Shaded rows indicate no produced material.

ID	Family	Genus	Species	Material	RAW_MAT (mg)	BEAKER (mg)	BEAKER_PEL (mg)	SLIDE (mg)	Notes	% yield
LMV001	Fagaceae	Quercus	velutina	leaf	516.46	28929.59	28929.85	0.6		0.12
LMV002	Fagaceae	Quercus	velutina	bark	501.4	30034.7	30036.28	0.29	all the bark	0.06
LMV003	Fagaceae	Quercus	phellos	leaf	234.64	30541.95	30542.31	2.22		0.95
LMV004	Fagaceae	Quercus	phellos	bark	517.04	30530.06	30529.53	0.13		0.03
LMV005	Cupressaceae	Juniperus	virginiana	leaf	243.92	30068.3	30068.84	0.74		0.30
LMV006	Cupressaceae	Juniperus	virginiana	bark	222.38	29046.24	29047.7	NULL	looks empty	NULL
LMV007	Fagaceae	Quercus	rubra	leaf	514.39	30124.08	30124.16	1.38		0.27
LMV008	Fagaceae	Quercus	rubra	bark	474.24	28929.55	28930.2	0.86	some kind of sand in the beaker	0.18
LMV009	Magnoliaceae	Magnolia	grandiflora	leaf	160.51	29931.75	29943.32	2.32		1.45
LMV010	Magnoliaceae	Magnolia	grandiflora	bark	547.5	30068.56	30071.48	1.61		0.29
LMV011	Fagaceae	Fagus	grandifolia	leaf	229.7	29966.31	29967.89	1.09		0.47
LMV012	Fagaceae	Fagus	grandifolia	bark	530.33	30035.36	30036.02	1.36		0.26
LMV013	Fagaceae	Quercus	michauxii	leaf	238.38	29046.34	29050.39	1.97		0.83
LMV014	Fagaceae	Quercus	michauxii	bark	395.23	30286.91	30289.14	0.58	all the bark	0.15
LMV015	Pinaceae	Pinus	virginiana	leaf	230.32	30530.02	30530.73	0.68		0.30
LMV016	Pinaceae	Pinus	virginiana	bark	502.61	29931.91	29932.24	NULL		NULL
LMV017	Fagaceae	Quercus	nigra	leaf	513.63	30174.29	30176.45	1.35		0.26
LMV018	Fagaceae	Quercus	nigra	bark	473.77	30529.95	30530.47	0.62		0.13
LMV019	Fagaceae	Quercus	coccinea	leaf	537	29593	29594	0.71		0.13
LMV020	Fagaceae	Quercus	coccinea	bark	519.09	29966.8	29966.58	0.06		0.01
LMV021	Fagaceae	Quercus	alba	leaf	217.45	29932.04	29932.91	0.65		0.30
LMV022	Fagaceae	Quercus	alba	bark	493.47	30068.6	30068.69	NULL		NULL
LMV023	Magnoliaceae	Liriodendron	tulipfera	leaf	506.39	29046.87	29046.95	0.66		0.13
LMV024	Poaceae	Microstegium	vimineum	leaf	118.64	30232.56	30234.35	1.27		1.07
LMV025	Poaceae	Brachyelytrum	erectum	leaf	110.29	29931.62	29940.14	2.11		1.91
LMV026	Poaceae	Andropogoneae	NULL	leaf	107.29	30173.74	30174.6	NULL		NULL
LMV027	Poaceae	Dicanthelium	NULL	leaf	64.36	29592.72	29594.6	1.31	all the material	2.04
LMV028	Poaceae	NULL	NULL	leaf	105.81	30231.99	30235.44	1.93		1.82
LMV029	Annonaceae	Asimina	triloba	leaf	535.89	30287.32	30288.98	1.37		0.26
LMV030	Annonaceae	Asimina	triloba	bark	528.65	30124.26	30124.18	0.32	looks like charcoal, imcomplete combustion	0.06

Appendix E

Table of the raw phytolith count data collected for the modern soil plot analyses. Total phytoliths per gram, dicot:monocot ratio, and multicell:singlecell ratio values calculated using the different morphotype phytolith per gram values. Plot longitude and latitude taken from Kribel (2003). Weight values are given in mg.

Sample	Plot	Latitude	Longitude	initial_wt	pellet_wt	slide_wt	mon_phyt/gram
LMS004	CAMP 1.2	37.27388333	-76.72281667	5147.43	2	2	214
LMS005	CAMP 5	37.265	-76.7222	5081.37	9.82	2.04	1731
LMS006	1	37.2733	-76.7263	5150.69	1.92	1.92	159
LMS007	2	37.2715	-76.7262	5075.63	2.86	2.86	148
LMS008	3	37.27133333	-76.72815	5091.07	0.2	0.2	315
LMS009	4	37.2699	-76.7298	5114.5	1.9	1.9	834
LMS010	5	37.26336667	-76.72985	5108.81	2.98	2.98	730
LMS011	6	37.26358333	-76.72931667	5150.26	2.99	2.99	692
LMS012	7	37.26423333	-76.72868333	5097.8	3.5	3.47	817
LMS013	8	37.26416667	-76.72416667	5140.46	2.51	2.51	819
LMS017	12	37.26721667	-76.72666667	5080.89	2.1	1.94	837
LMS019	14	37.27068333	-76.7309	5081.34	4	2.05	4949
LMS020	15	37.27056667	-76.72471667	5101.07	3.08	2.07	1566
LMS023	18	37.2771	-76.7244	5107.47	6.09	2.03	814
LMS024	19	37.26445	-76.73596667	5115.48	4.4	2.09	2143

dicot_phyt/gram	multi_monocot/g	multi_dicot/g	multi_phyt/gram	phyt/gram	D_M_ratio	multi/single_ratio
80	1	1	2	305	0.272108844	0.006514658
818	11	8	19	2558	0.320910161	0.007372914
68	2	0	2	237	0.299559471	0.008368201
31	0	0	0	185	0.173184358	0
131	2	2	4	459	0.293721973	0.008639309
215	1	0	1	1056	0.204957102	0.000946074
160	0	0	0	890	0.179775281	0
197	3	2	4	892	0.2215973	0.004464286
146	6	2	8	969	0.151609553	0.008188332
224	1	0	2	1050	0.214765101	0.001901141
220	2	0	2	1083	0.208136235	0.001843318
3290	9	6	15	8322	0.399320306	0.001799208
687	11	6	17	2299	0.304926764	0.007340242
387	4	0	4	1208	0.322231474	0.00330033
565	14	11	25	2735	0.208641064	0.009057971

pH	Elevation (m)	Slope	Surrounding_veg	Veg type	Creek
7.61	8.23	1.07	Under microstegium	Wetland	College
4.92	10.95	3.98	Fabaceae, Sassafrass, Vaccinium, Holly	Shrub	College
5.68	21.69	15.09	Beech, Q. alba, Holly, Q. rubra	Mixed	College
5.67	22.73	7.44	Beech, Sweetgum	Hardwood	College
5.53	22.86	1.54	Beech, Maple	Hardwood	Pogonia
5.45	21.52	3.55	Holly, Dogwood, Maple	Hardwood	Pogonia
5.08	22.30	7.08	Holly, Beech, Q. alba, Maple	Hardwood	Strawberry
5.09	21.16	4.22	Maple, Beech, Q. alba, Holly	Mixed	Strawberry
5.01	19.37	3.76	Beech, Maple, Q. alba	Mixed	Strawberry
5.96	16.35	5.35	Sweet gum, Beech, Hickory, Holly	Mixed	College
5.16	11.78	20.43	Holly, Beech, Q. velutina, L. A. Wood Grass	Mixed	Strawberry
4.9	9.72	4.08	Loblolly, Maple, Beech	Mixed	Pogonia
4.9	22.98	3.94	Beech, Q. alba, Holly, Magnolia	Mixed	College
6.73	8.93	13.55	No notes (wetland)	Wetland	College
5.43	31.35	1.98	Beech, Dogwood, Holly, Blueberry, Q. alba	Shrub	Strawberry

Appendix F

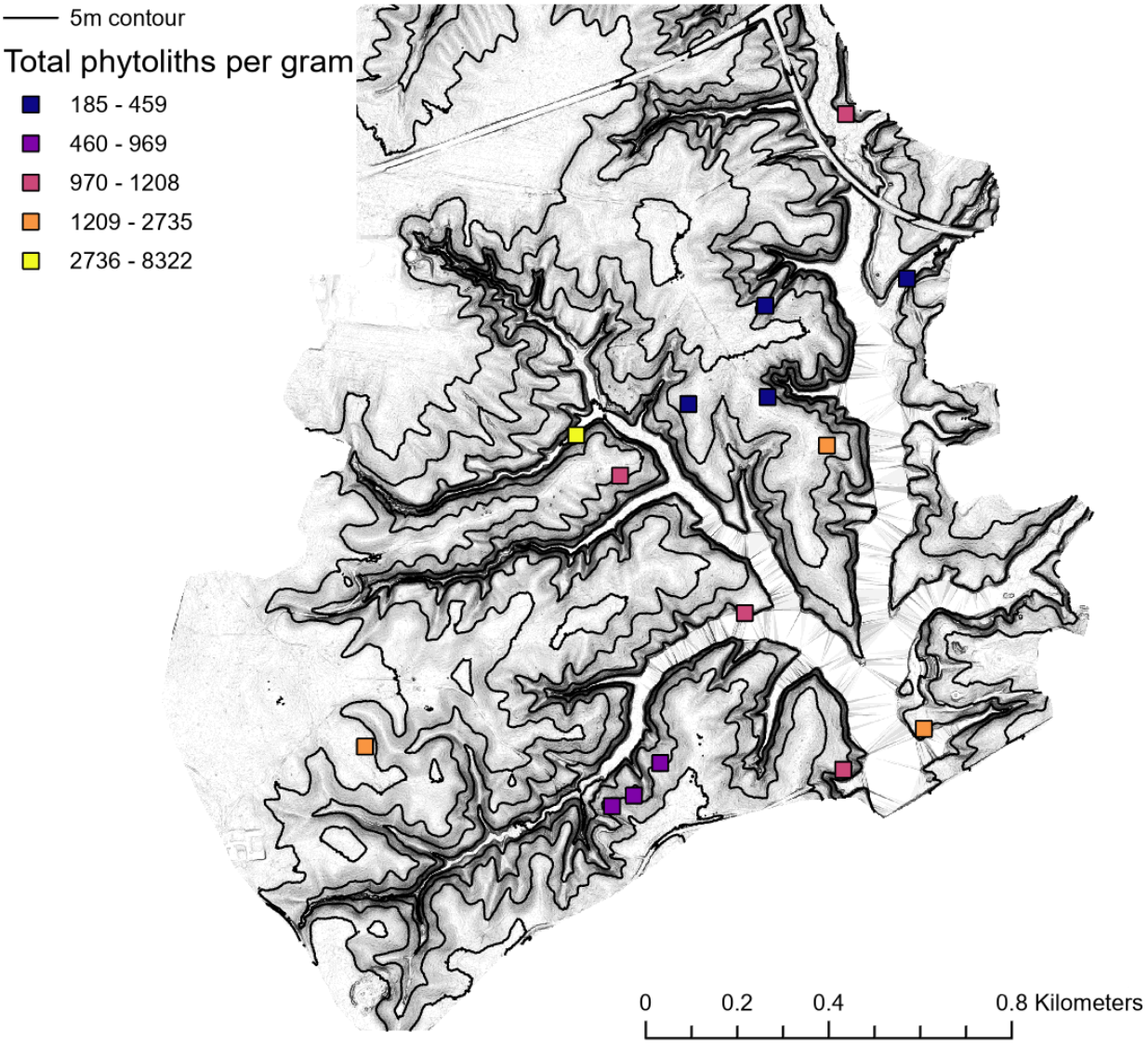
Table of modern soil samples and the reactions during carbonate removal using 10% HCl and the number of washes each sample underwent during deflocculation using 5% $NaPO_4$. LMS006-LMS0013 did not have the specific number of washes recorded but took the same amount of time as the other samples.

Sample ID	HCl Reaction	Deflocculation washes
LMS004	none	6
LMS005	none	7
LMS006	none	not recorded
LMS007	none	not recorded
LMS008	none	not recorded
LMS009	none	not recorded
LMS010	none	not recorded
LMS011	none	not recorded
LMS012	none	not recorded
LMS013	none	not recorded
LMS017	none	7
LMS019	none	8
LMS020	none	7
LMS023	none	8
LMS024	none	6

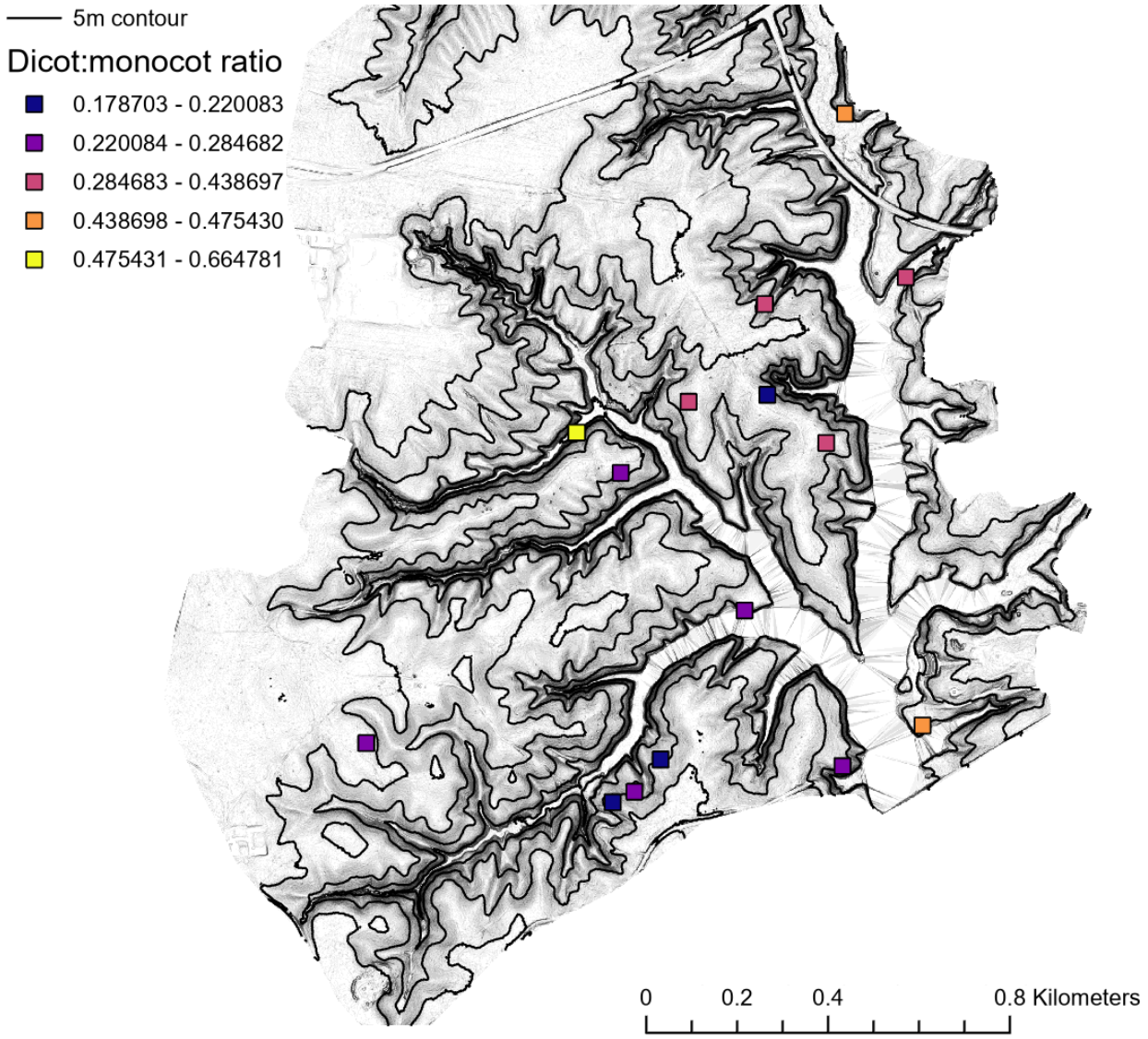
Appendix G

Maps of the plot values for the total phytoliths per gram, dicot:monoct ratio, multicell:singlecell ratio, pH, slope, and elevation. Elevation and slope are also given by the contour lines and the base map. All maps generated in ArcGIS Pro using three-meter LIDAR data via USGS.

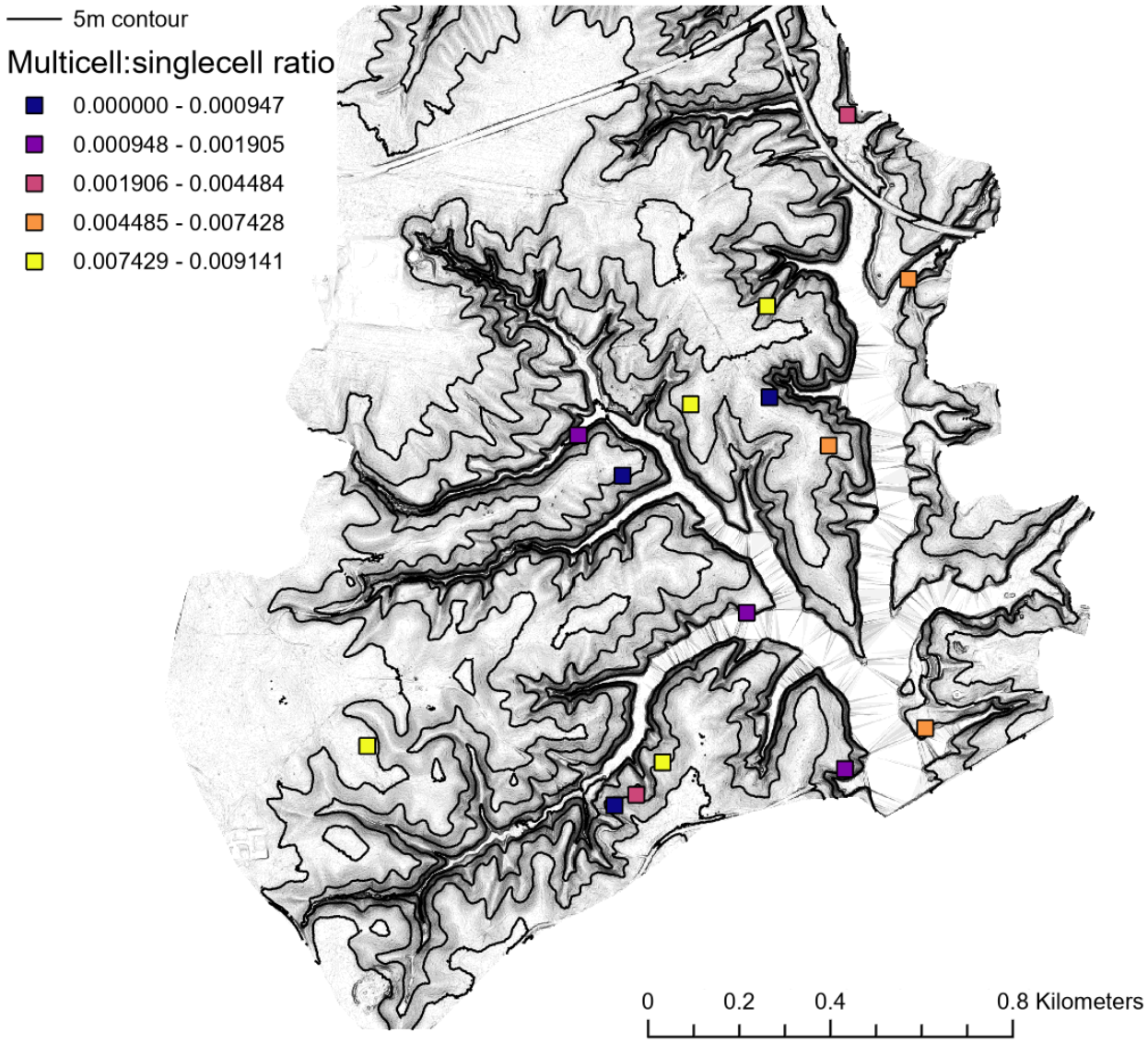
Map of the range of total phytoliths per gram values. Note plot 14 with the highest value in yellow.



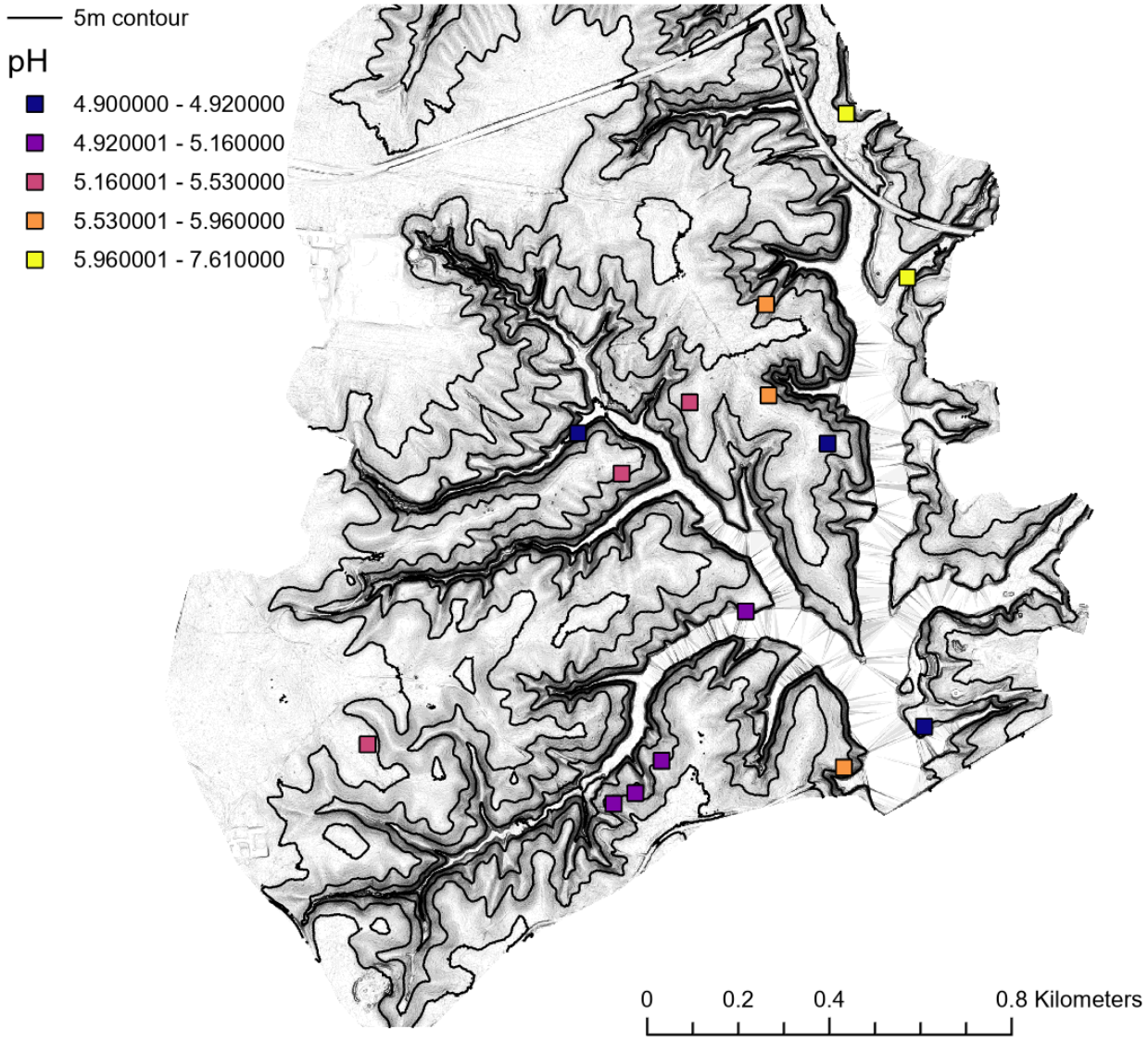
Map of the range of dicot:monocot ratio values. Note plot 14 with the highest value in yellow.



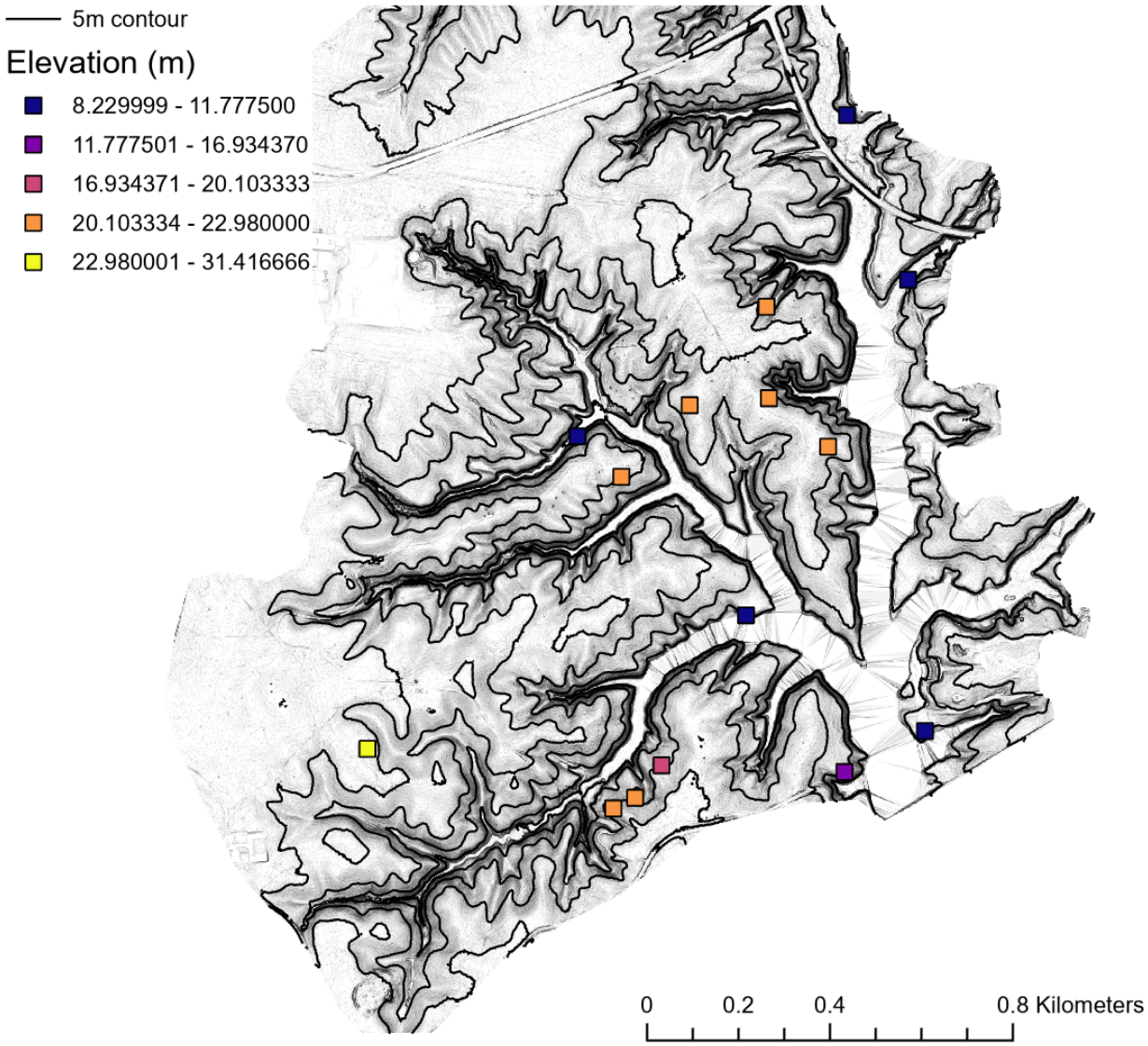
Map of the range of multicell:singlecell ratio values.



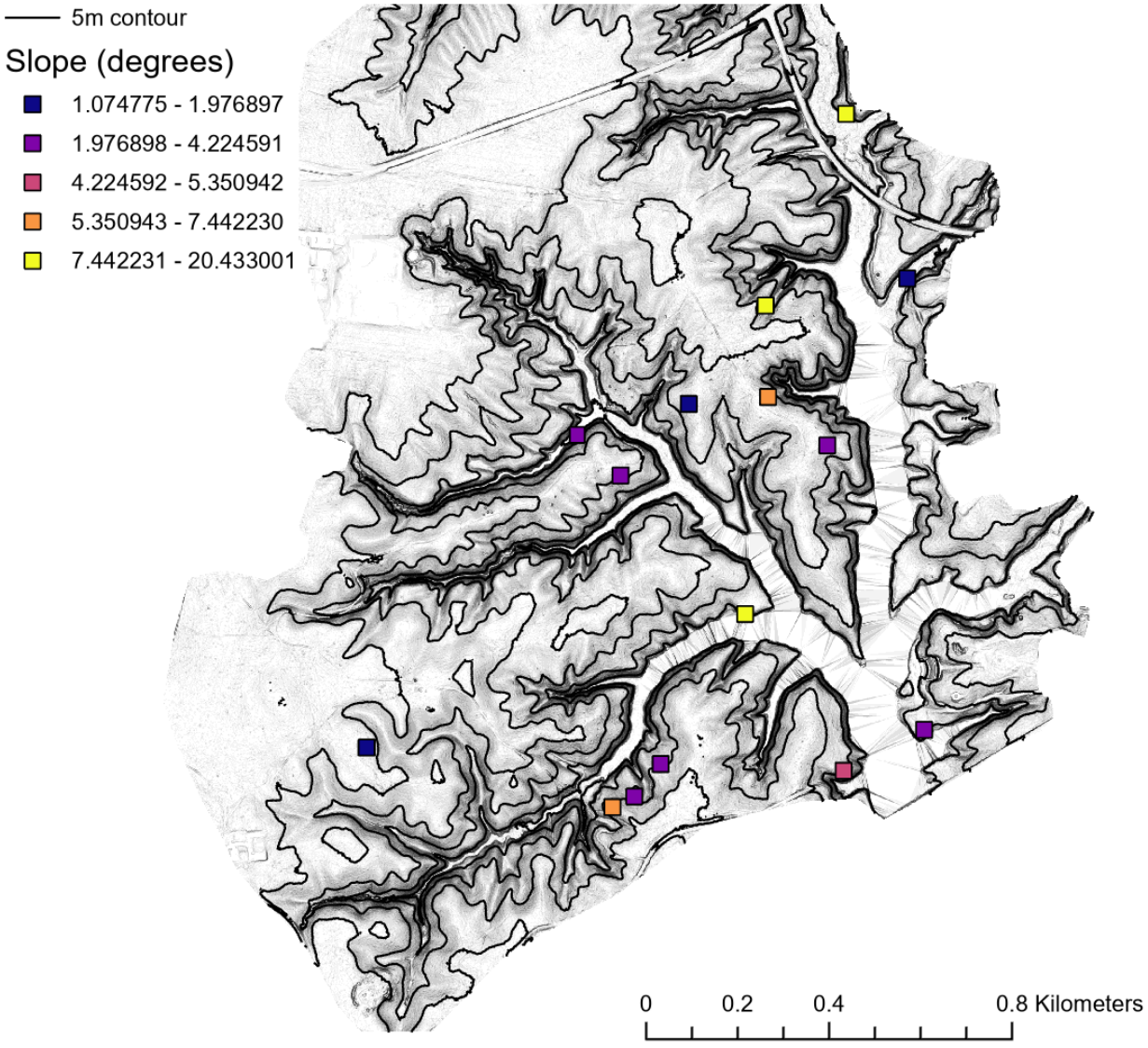
Map of the range of pH values. Note that the two wetland samples, P18 and C1.2, have the highest pH values. pH values measured to the hundredth of a pH, legend contains additional values not relevant.



Map of the range of elevation values.



Map of the range of slope values.



Appendix H

Table of the phytolith counts for the 5 lake samples from core LMP-03-16. Columns represent the same values as the modern soil plots. All weights are given in mg.

SampleID	Lab #	Depth (cm)	Age	initial_wt	pellet_wt	slide_wt	mon_phyt/gram	dicot_phyt/gram	multi_monocot/gram
LMP001	1	0.0-31.5	~2016-1960	5665.6	10.69	2.28	2371	1204	2
LMP002	2	31.5-63.0	~1960-1890	5824.79	22.3	2.43	3546	1496	9
LMP003	3	63.0-94.5	~1890-1810	5368.2	14.82	2.32	3993	1148	5
LMP004	4	94.5-126.0	~1810-1700	5304.83	22.74	2.03	12440	4036	34
LMP005	5	126.0-150.0	pre 1700	5954.39	4.67	2.25	621	465	2

multi_dicot/gram	multi_phyt/gram	phyt/gram	D_M_ratio	multi/single_ratio	pH	notes
2	3	3575	0.336783217	0.000838457	6.79	charcoal
6	16	5042	0.296707656	0.003163306	6.71	charcoal
0	5	5141	0.223302859	0.000971628	6.93	lots of diatoms
4	38	16807	0.24496237	0.002255862	7	lots of diatoms
1	3	1104	0.428176796	0.002710027	6.74	

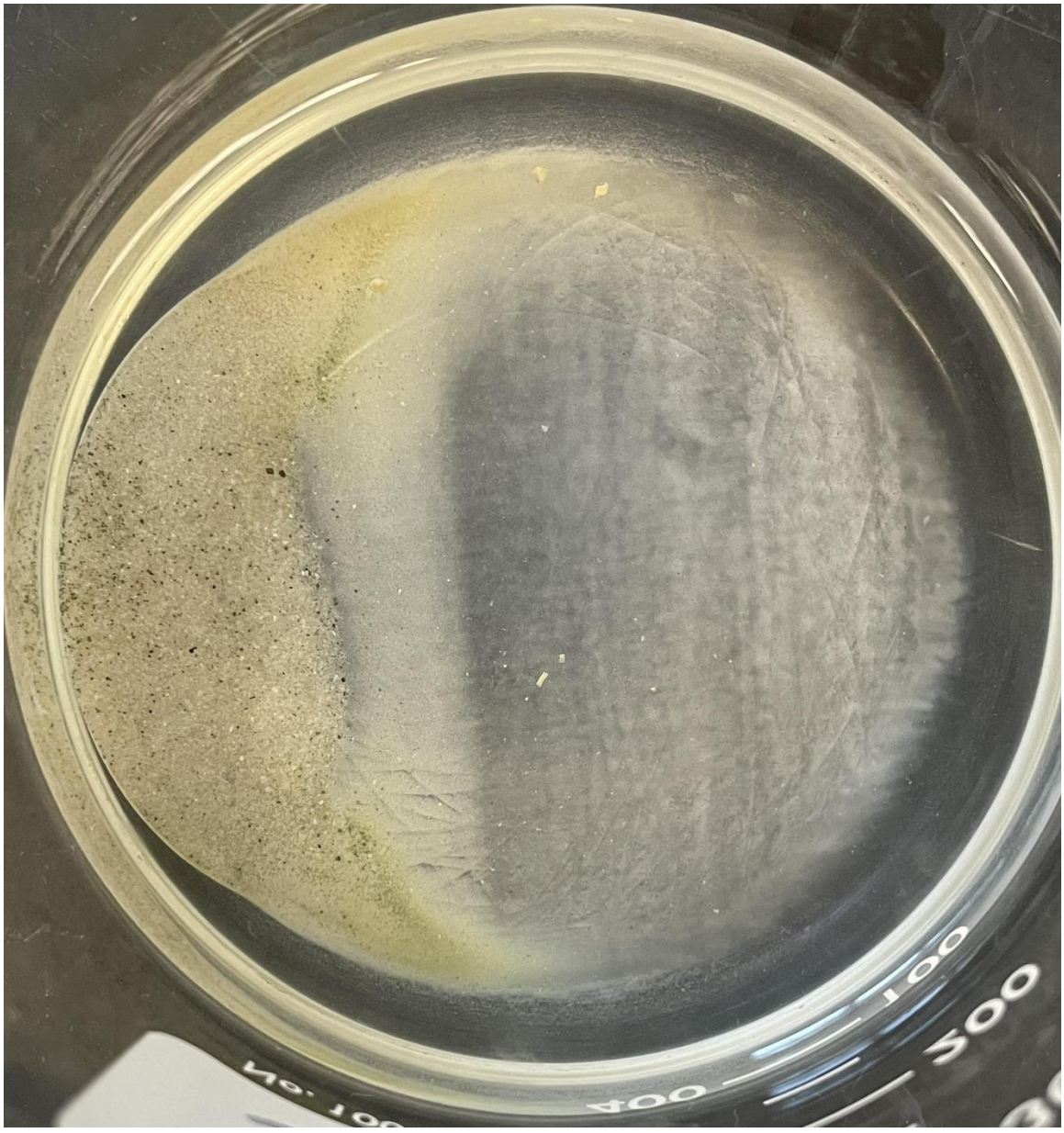
Appendix I

Table of the recorded reactions during carbonate removal and organic removal. Record of reaction was taken at the onset of the process. Note that LMP005 is recorded as not reacting during carbonate removal. The reaction may have been occurring, but it did not produce vigorous enough bubbling to be recorded initially.

SampleID	HCl Reaction	H_2O_2 Reaction	Notes
LMP001	Yes	Yes	Started with 5% H2O2 for 24 hours
LMP002	Yes	Yes	
LMP003	Yes, right away	Yes	
LMP004	Yes	Yes	
LMP005	No	Not really, less than others	longest reaction, was still going after 6 days, lost the most material, changed colors completely after

Appendix J

Photo of LMP005 (pre-lake) sediment following carbonate removal and organics removal. Note the high quantity of sand in the sample as well as the green silt-sized minerals at the edge. These green minerals are what I interpreted to be glauconite.



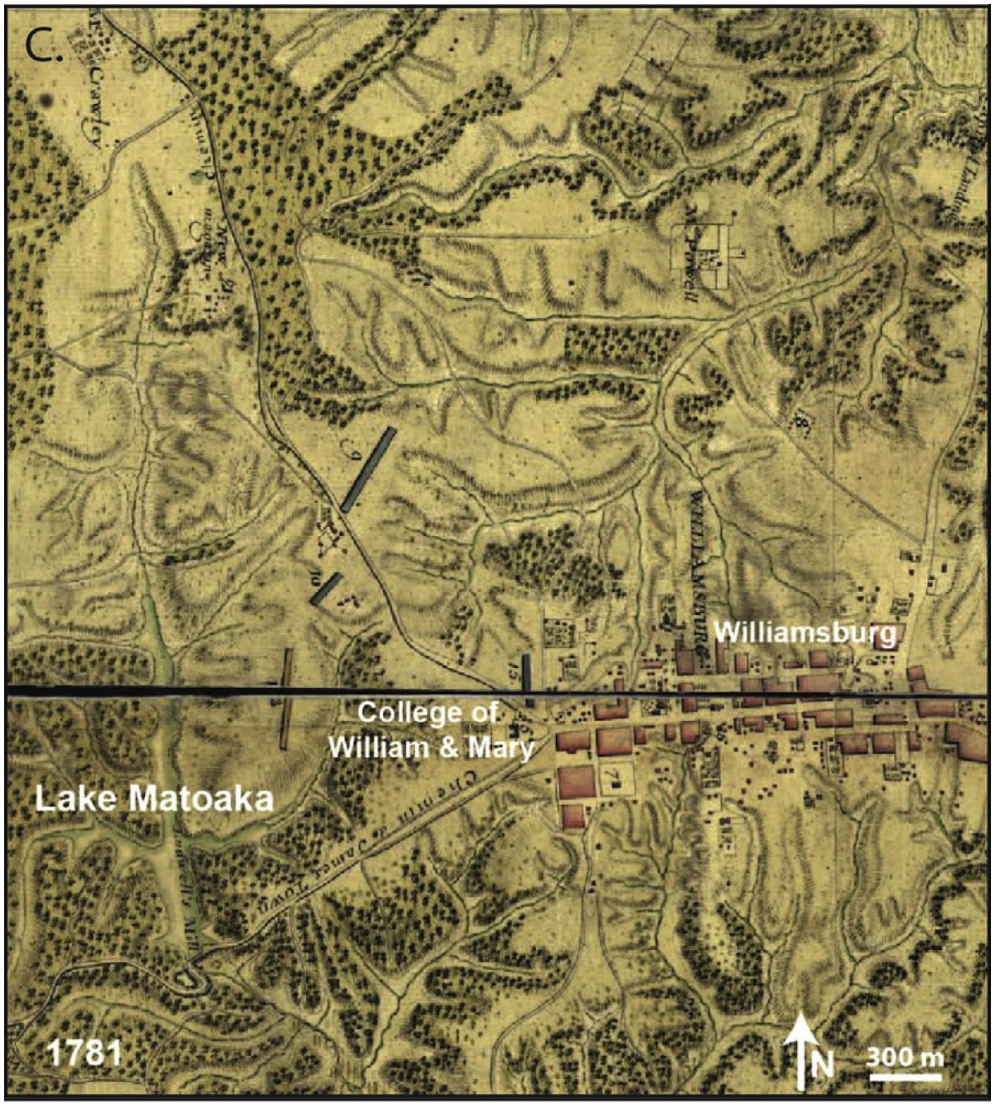
Appendix K

Plat of Thomas Ballard property in modern-day Williamsburg, Virginia. Survey of the area done in 1678. Note Archer's Hope Swamp is located in the land now covered by Lake Matoaka.

Figure via Monroe and Lewes (2016).

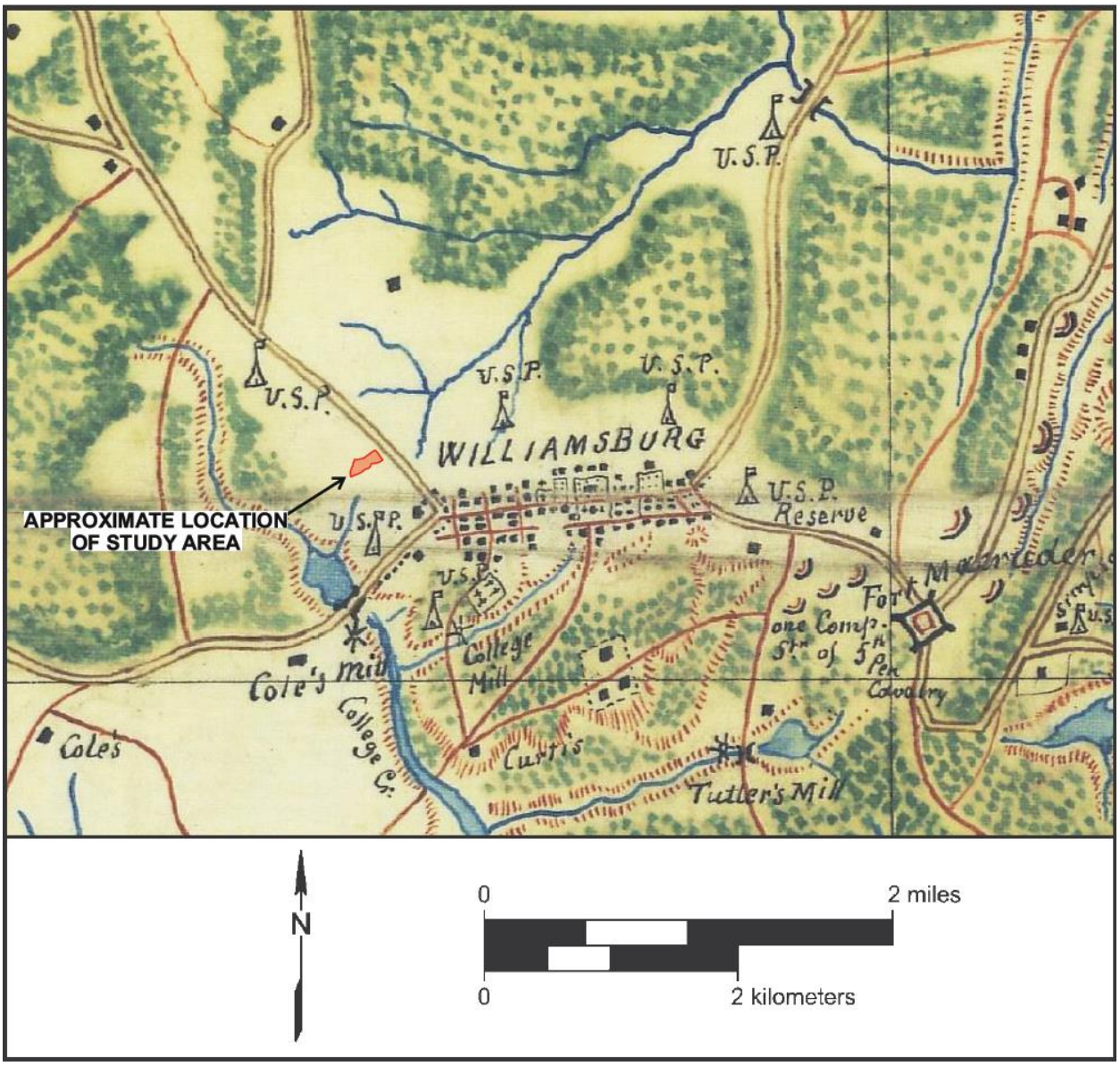
Appendix L

Map of the Williamsburg area created in 1781 by the French Military during the Revolutionary War. Figure modified from Balascio et al. (2019).



Appendix M

Map of the Williamsburg region in 1862. Map created by the Union Army engineers. Note the smaller Lake Matoaka as an indication of the ruptured dam. Figure via Monroe and Lewes (2016).



Appendix N

Images of evidence of dissolution on phytoliths within the assemblages of the College Woods.

Magnification 400X.

Image of dissolution pits on Keystone phytolith morphotype in modern soil.

Image of dissolution pits on phytoliths within modern soil samples.

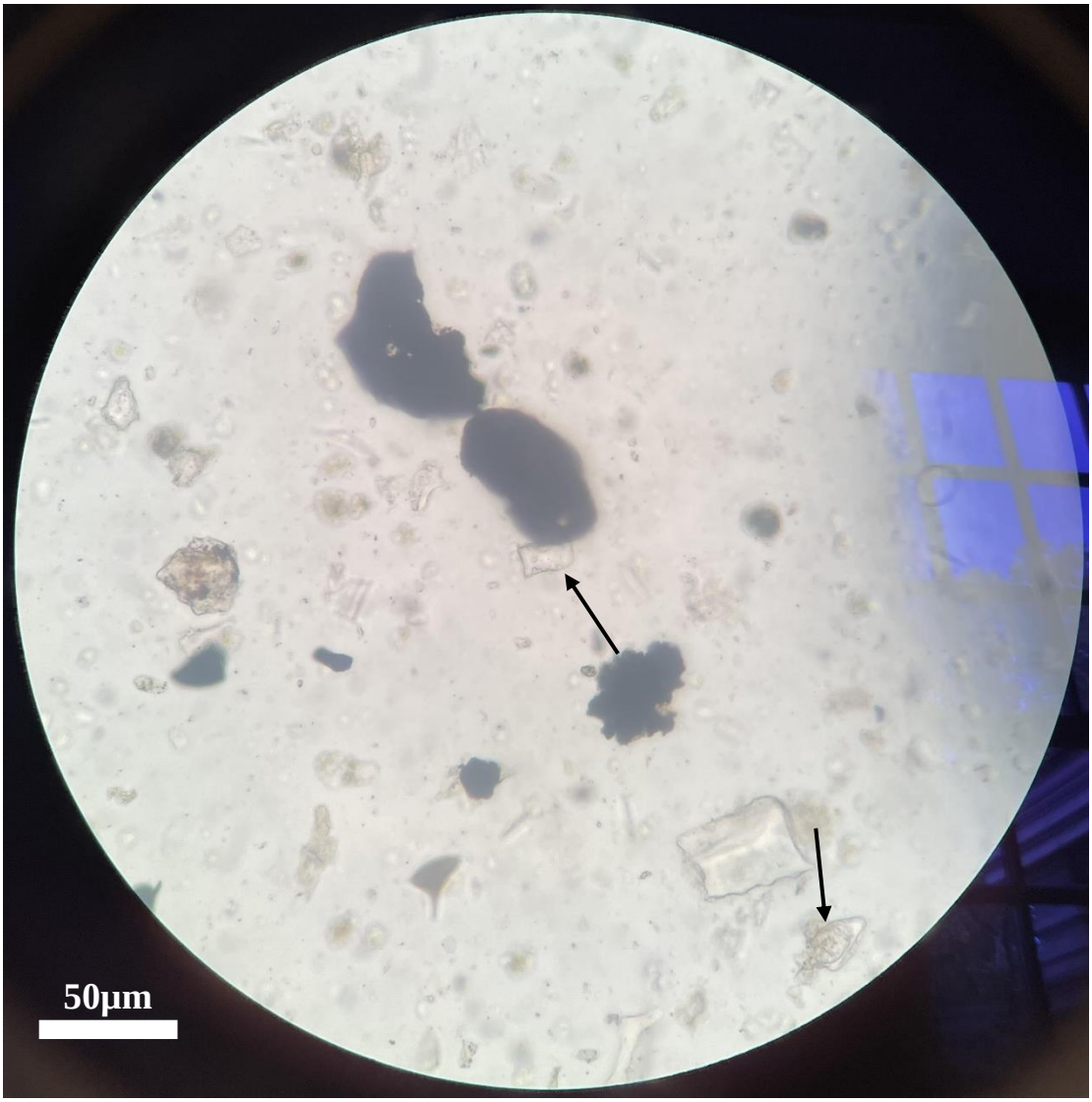
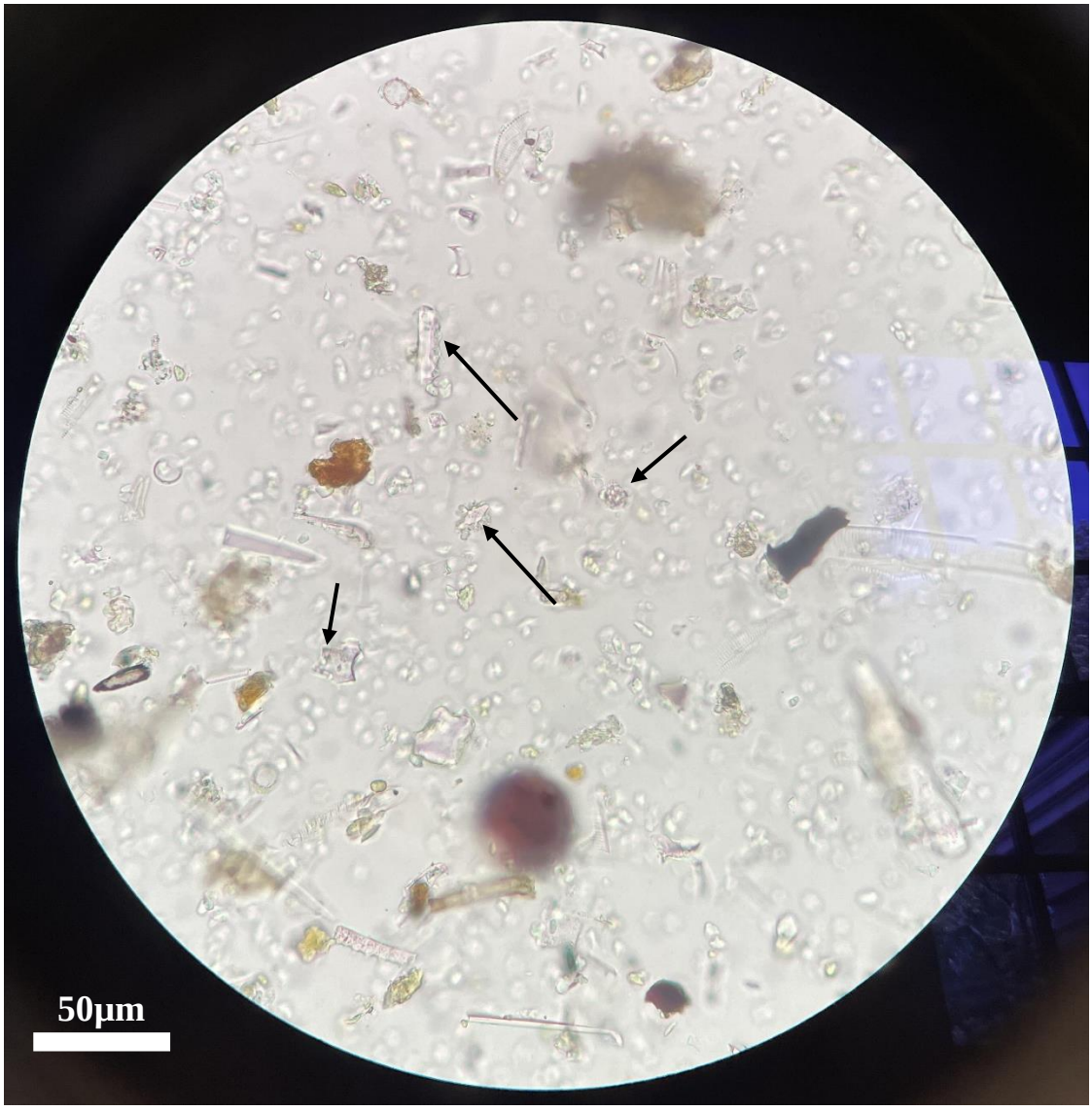


Image of dissolution pits on phytoliths within the lake sediment core (LMP-03-16).



Appendix O

Image of diatoms extracted with the phytolith assemblages of the lake sediment core LMP-03-16. Magnification 400X. Two diatom fragments labeled with arrows.

Appendix P

Images of charcoal fragments extracted from the lake sediment core LMP-03-16 with the phytolith assemblages. Note the two charcoal types, round ash particles and irregular charcoal fragments Magnification 400X.

Image of charcoal fragments within the modern sediment of the lake sediment core (LMP-03-16).

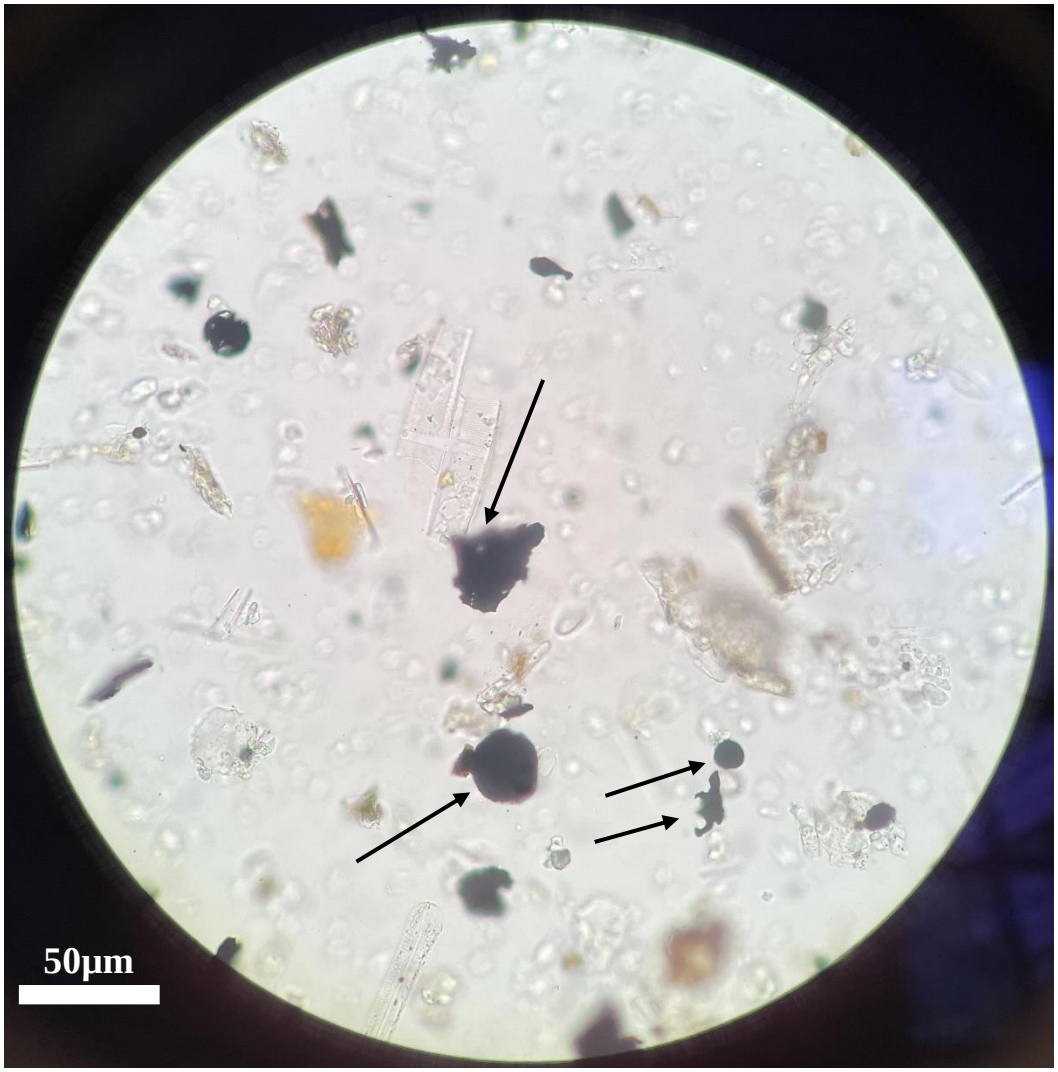


Image of charcoal fragments within the ~1960-1890 sample of the lake sediment core (LMP-03-16).

Image of charcoal fragments within the ~1890-1810 sample of the lake sediment core (LMP-03-16).

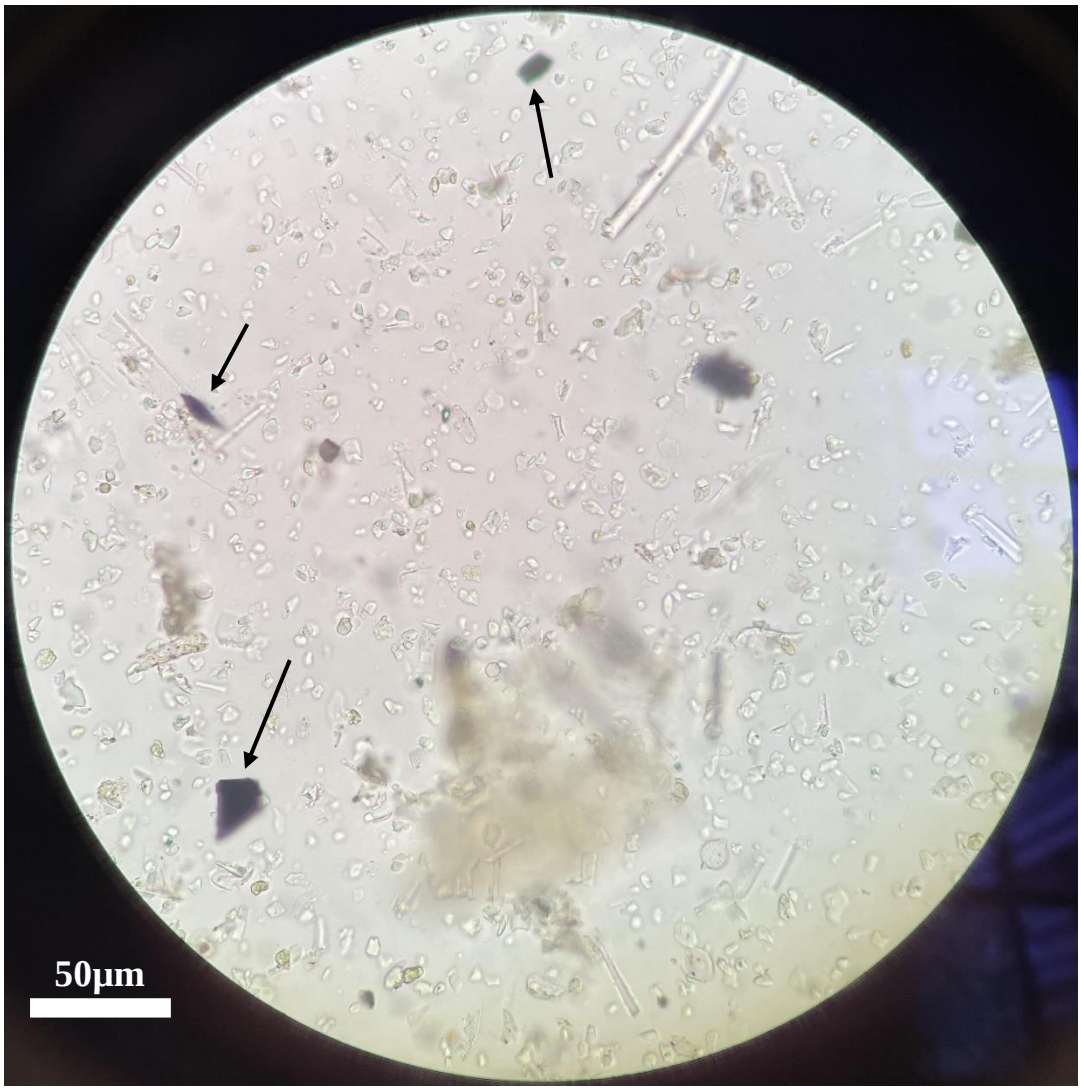


Image of charcoal fragments within the early lake sample of the lake sediment core (LMP-03-16).

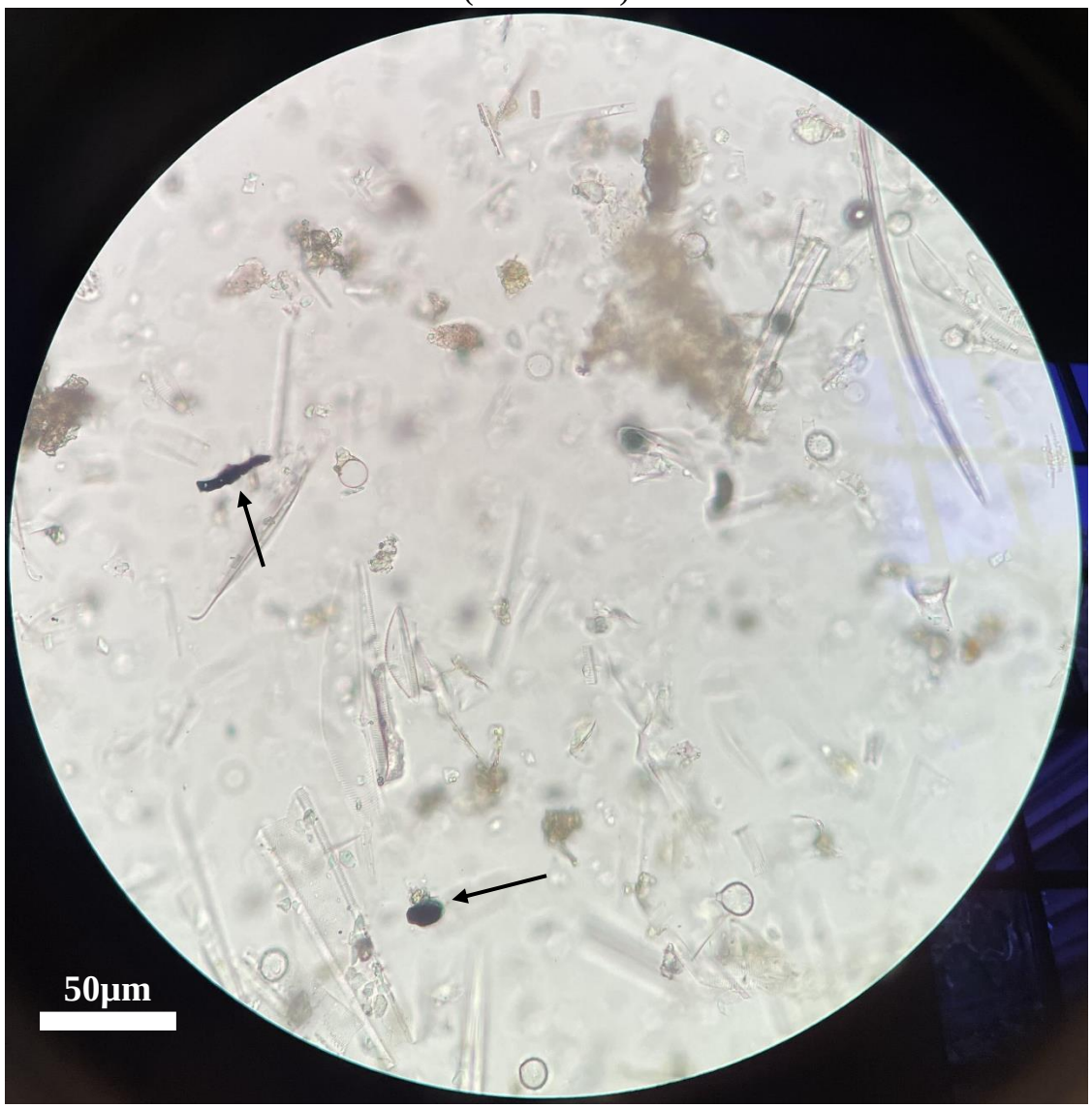
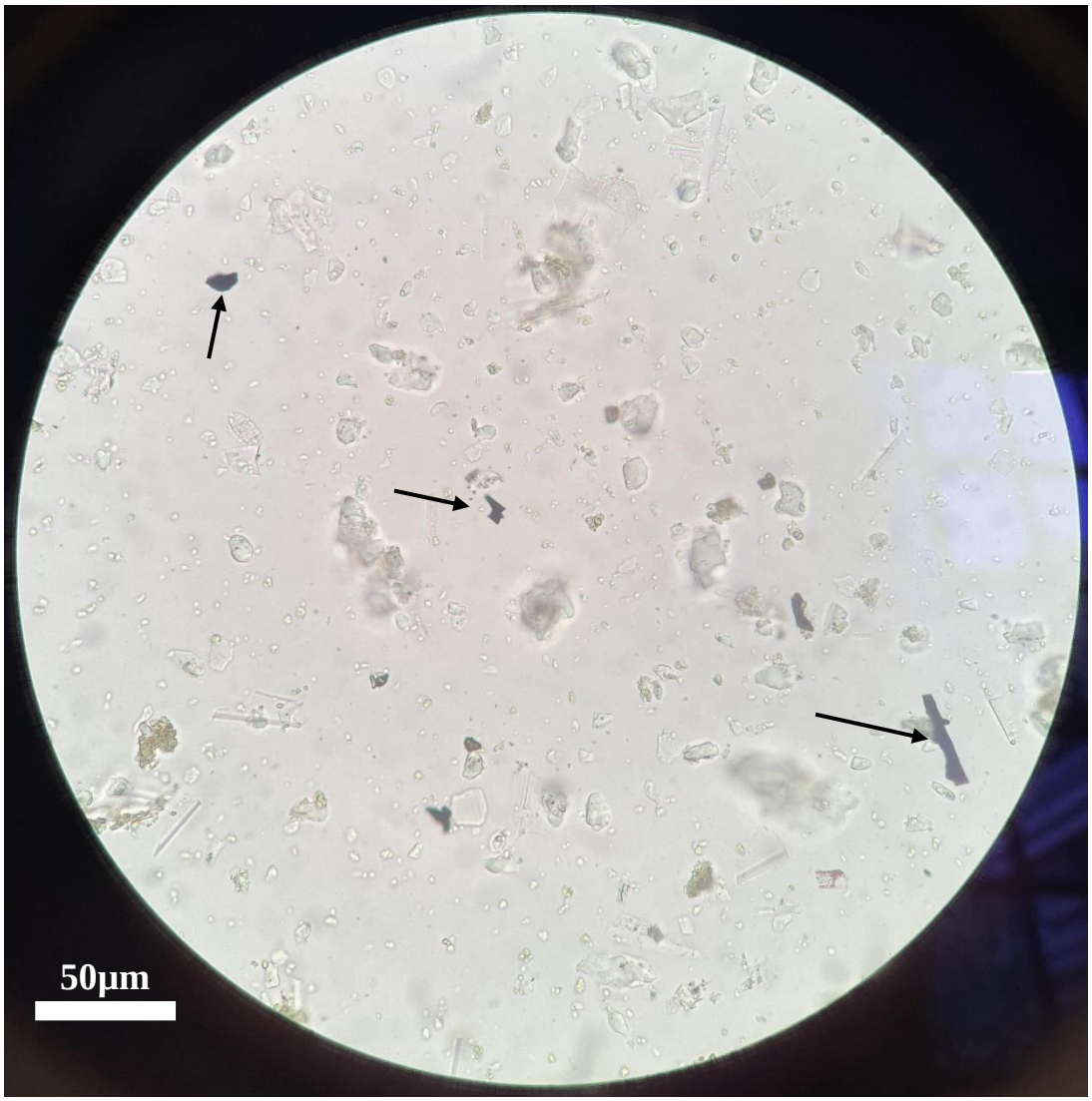


Image of charcoal fragments within the pre-lake sample of the lake sediment core (LMP-03-16).



Appendix Q

Figure of the number of publications involving phytolith studies of the different plant families. Note that Fagaceae, the family encompassing both oaks and beech is severely lacking in attention for how important the taxa are on the Eastern United States. Figure via Sharma et al. (2019). Arrows indicate families used in this study, Magnoliaceae not listed.

Appendix R

Tables of the p-value results of the statistical tests done in R Studio.

P-values of the Shapiro-Wilk normality tests. Note dicot:monocot ratio is the only significant result.

Variable	Shapiro-Wilk
phytoliths/gram	4.59E-05
dicot:monocot ratio	0.345
multicell:singlecell ratio	0.0458
pH	0.00312
elevation	0.0906
slope	0.00368

P-values of the two-sided Wilcoxon single rank tests for non-parametric data. The shaded dicot:monocot ratio indicates the use of a two-tailed t-test due to normality.

Variable	Highland (>20m)	Lowland (≤20m)
phytoliths/gram	0.232	0.232
dicot:monocot ratio	0.0543	0.132
multicell:singlecell ratio	0.862	0.862
pH	0.908	0.908
slope	0.779	0.779

P-values of the Kruskal-Wallis tests for influence by creek watershed and by surrounding vegetation.

Variable	Creek	Surrounding Vegetation
phytoliths/gram	0.754	0.148
dicot:monocot ratio	0.114	0.305
multicell:singlecell rati	0.910	0.227
pH	0.285	0.120
elevation	0.695	0.085
slope	0.349	0.577